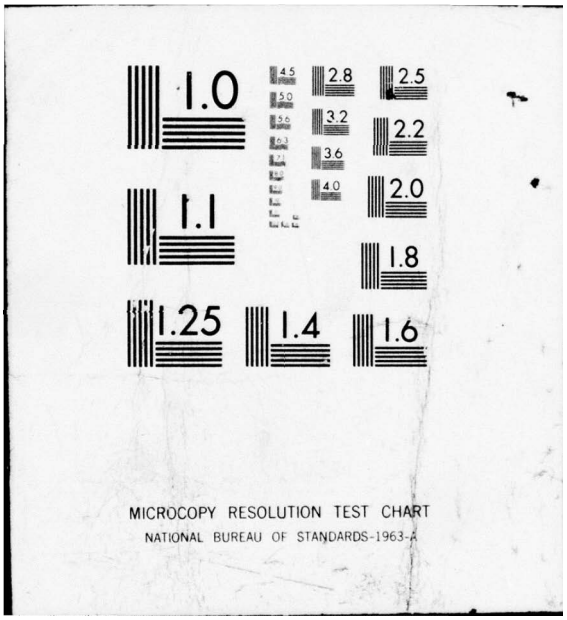
AD-A031 080 MICHIGAN UNIV ANN ARBOR COASTAL ZONE LAB F/G 13/2
PILOT STUDY PROGRAM, GREAT LAKES SHORELAND DAMAGE STUDY. APPEND--ETC(U)
MAY 76 B A STOKER DACW23-75-C-0027

UNCLASSIFIED NL

| OF |
AD
A031080



END
DATE FILMED
11-76


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A031080

APPENDIX VII

# MEASUREMENT OF COASTAL BLUFF RECESSION FROM AERIAL PHOTOGRAPHS, MUSKEGON COUNTY, MICHIGAN

by

Bruce Alexander Stoker

Coastal Zone Laboratory
The University of Michigan

NCW 409887

DDC RECEIVED OCT 22 1976 C

Recession rates given in this appendix may not agree with other available recession rate information. The exact cause for this discrepancy has not been determined at this time. It may be due to measurement error which this appendix documents.

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. (6)

3. RECIPIENT'S CATALOG NUMBER

4. TITLE *(and Subtitle)* ~~Summary Report of the~~ Pilot Study Program, Great Lakes Shoreland Damage Study, ~~(three volumes, see reverse side)~~ Appendix VII, Measurement of Coastal Bluff Erosion from Aerial Photographs, Muskegon, County, Michigan.

5. TYPE OF REPORT & PERIOD COVERED (9) Final rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

(10) Bruce A. Stoker Alexander

8. CONTRACT OR GRANT NUMBER(s)

(15) DACW23-75-C-0027 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Coastal Zone Laboratory, University of Michigan
1101 North University Building
Ann Arbor, Michigan 48104

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

North Central Division, Corps of Engineers
536 S. Clark Street
Chicago, Illinois 60605

12. REPORT DATE (11) May 1976

13. NUMBER OF PAGES 59

14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)* (12) 67p.

15. SECURITY CLASS. *(of this report)* Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release, distribution unlimited.

D D C
RECEIVED
MAY 22 1976
C

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service, Springfield, Virginia 22151

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

aerial photographs
erosion (recession rate)
coastal zone
Great Lakes

This appendix evaluates

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This is an appendix to the Summary Report of the Pilot Study Program, Great Lakes Shoreland Damage Study. Its purpose is to evaluate the usefulness of aerial photographs in the determination of coastal erosion rates. The effectiveness of aerial photographs was examined in terms of availability, type of coverage, and the reliability of the measurements obtained from the photographs.

(cont on p. 42)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

409 882

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

| | |
|---|---|
| Main Report | Summary Report of the Pilot Study Program, Great Lakes Shoreland Damage Study. |
| Appendix I | Great Lakes Shoreline Damage Survey; St. Louis County, Minnesota |
| Appendix II | Great Lakes Shoreline Damage Survey; Brown, Douglas, and Racine Counties, Wisconsin |
| Appendix III | Great Lakes Shoreline Damage Survey; Muskegon, Manistee, Schoolcraft, Chippewa, Alcona, and Huron Counties, Michigan |
| Appendix IV | Contract for a Damage Survey of Oswego County, New York |
| Appendix V | Shoreline Damage Survey: An Appraisal with Recommendations |
| Appendix VI | Engineering - Economic Analysis of Shore Protection Systems: A Benefit/Cost Model |
| Appendix VII | Measurement of Coastal Bluff Recession from Aerial Photographs, Muskegon County, Michigan |
| Appendix VIII | Comparison of Field Data Collection to Date Collected Using Study Instruments in Muskegon and Manistee Counties, Michigan |

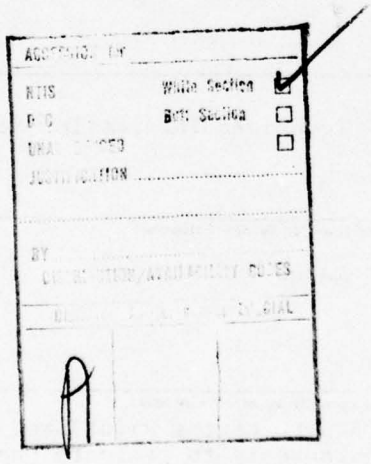


TABLE OF CONTENTS


| | Page |
|---|---|
| LIST OF TABLES | iii |
| LIST OF ILLUSTRATIONS | iv |
| LIST OF PHOTOGRAPHS | vi |
| INTRODUCTION | 1 |
| METHODOLOGY | 2 |
| ERRORS | 6 |
| Measurement Errors | 6 |
| Relief Displacement Error | 6 |
| Tilt | 8 |
| Interpretation Errors | 9 |
| Methods to Lessen Errors | 12 |
| AREA I | 13 |
| AREA II | 18 |
| AREA III | 23 |
| AREA IV | 31 |
| ANALYSIS OF METHODS AND DATA | 39 |
| CONCLUSIONS | 42 |
| REFERENCES | 43 |
| APPENDICES | |
| K-I Index of Aerial Imagery for Coastal Areas of Michigan | 45 |
| K-II List of Photos Used | 55 |
| K-III Measurements for All Sites | 57 |

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1. | Erosion Data for Area I. . . . . | 15 |
| 2. | Erosion Data for Area II . . . . . | 21 |
| 3. | Erosion Data for Area III. . . . . | 26 |
| 4. | Erosion Data for Area IV . . . . . | 34 |
| 5. | Sand Wave Data . . . . . | 35 |
| 6. | Lake Levels for Dates of Photo Coverage. . . . . | 35 |

## LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| 1. | General Profile, case 1. | 2 |
| 2. | Location of Test Areas in Muskegon County. | 4 |
| 3. | General Profile, case 2. | 7 |
| 4. | Projection of Radial Displacement into Direction of Recession Measurement | 8 |
| 5a-c. | Edge Gradient, Three Cases | 10 |
| 6. | Location Ambiguities | 10 |
| 7. | Location of Sites in Area I. | 14 |
| 8. | Scale Variations, Area I | 16 |
| 9. | Generalized Profiles, Site 1 | 16 |
| 10. | Generalized Profiles, Site 2 | 17 |
| 11. | Generalized Profiles, Site 3 | 17 |
| 12. | Location of Sites in Area II | 19 |
| 13. | Generalized Profiles, Site 4 | 22 |
| 14. | Generalized Profiles, Site 5 | 22 |
| 15. | Generalized Profiles, Site 6 | 22 |
| 16. | Location of Sites in Area III. | 24 |
| 17. | Generalized Profiles, Site 7 | 28 |
| 18. | Generalized Profiles, Site 8 | 29 |
| 19. | Generalized Profiles, Site 9 | 29 |
| 20. | Generalized Profiles, Site 10. | 30 |
| 21. | Generalized Profiles, Site 11. | 30 |
| 22. | Location of Sites in Area IV | 32 |
| 23. | Generalized Profiles, Site 12. | 38 |

LIST OF ILLUSTRATIONS (continued)


| Figure | | Page |
|---|---|---|
| 24. | Generalized Profiles, Site 13. . . . . | 38 |
| 25. | Generalized Profiles, Site 14. . . . . | 38 |
| 26. | Total Recession Rates. . . . . | 40 |

## LIST OF PHOTOGRAPHS


| Photo | | Page |
|---|---|---|
| 1. | Beach and Bluff at Site 5. . . . . | 20 |
| 2. | Copy of Aerial Photo of Area IV. . . . . | 33 |
| 3. | Beach and Bluff at Site 14 . . . . . | 37 |

## INTRODUCTION

There are many coastal areas of the Great Lakes which are currently experiencing severe bluff erosion. Information relating these high erosion rates to long-term erosion data would be very useful for environmental planning and land use classification of coastal areas.

This study was undertaken to evaluate the usefulness of aerial photographs in the determination of coastal erosion rates. The effectiveness of aerial photographs was examined in terms of availability, type of coverage, and the reliability of the measurements obtained from the photographs.

The general procedure followed in this study was to locate existing aerial photographs, selecting and obtaining those pertinent to the erosion areas. Further steps involved selecting tentative site locations, making field observations and ground measurements, taking photograph measurements and deriving erosion rate calculations. The entire procedure was used only in Muskegon County, yet should be fairly representative of the state of Michigan.

## METHODOLOGY

The sources of aerial photographs were examined for locations covering the desired coastal areas, the widest possible range of years covered, and accessibility to the photographs. The organizations included in the study are summarized on pages 51-54 of this report. After studying the list of available photographs, sets covering as many years as possible were either purchased, borrowed for short periods of time, or examined at the respective offices. This review made it possible to choose (several) possible site locations for obtaining measurements. Sites were chosen on the basis of image indications of erosion, clear ground landmarks for making photographic measurements, and a relatively near ground control which could be used for the ground measurements.

Methods for obtaining measurements from aerial photographs involved the selection near each site of two distinct fixed geographic points. The distance between these two control points was measured in order to create a scale. Photograph measurements were then made from one of the scale control points, or from some permanent and distinct site nearby, to the bluff line (BL), toe line (TL) or dune line (DL), water line (WL) and first bar line (BR). (See Figure 1.) In some cases the vegetation line (VgL) and foredune line (DL) were measured.

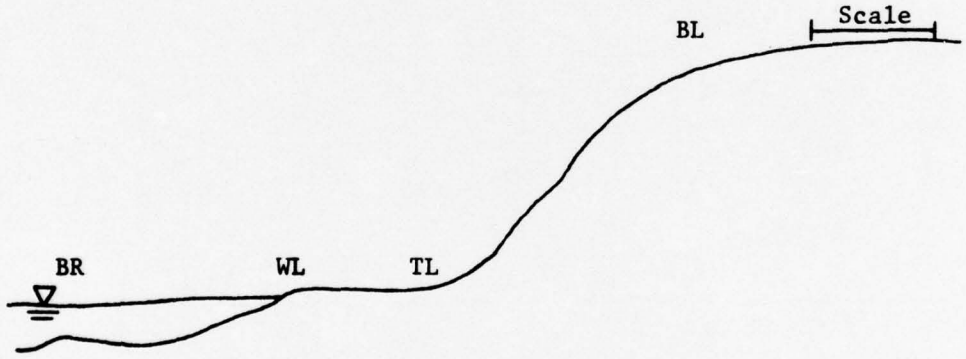



Figure 1. General profile shape case 1, indicating bluff line (BL), toe line (TL), water line (WL), bar line (BR), and scale control points.

Calculations were made to determine the change in bluff line location (DBL) and the rate of change in the bluff line (RBL) in total feet and feet per year. Changes and rates of change were also

noted for the toe line (DTL, RTL), water line (DWL, RWL), and the bar line (DBR). Further calculations were made of beach widths (WL-TL), profile width (TL-BL), and the distance of the first bar from shore (BR-WL).

A record of bar locations is also useful since offshore bars lessen wave energy reaching the shoreline. Note that bar width, bar distance from shore, and the number of bars vary greatly with storm activity, time of year, and lake levels. Offshore bar data can only be considered with these varying conditions in mind. The same conditions apply to beach width, as they also vary greatly with storm activity, time of year, and lake levels.

For this study, the bluff line will be defined as the major break in slope from the elevation of stable coastal material to the beach, as shown in Figure 1. This definition is useful for environmental planning since it divides areas that are stable from those that are affected by active processes, such as soil creep and wave and wind action. The rate of change in the bluff line distance will aid in defining the future extent of the stable zone.

Toe lines were generally located where the slope first leveled out onto the beach. Bars were located by measuring on the photographs from the shoreline to the center of the lightest tone area in the water.

Photograph measurements (measurements from the photographs) were done on a large table where the stereo pair for each year of coverage could be easily surveyed. Diagrams and general sketches of the profile shape were made for each site, noting measurement points, vegetation changes, land use changes, and any other interesting observations. A six-inch dial caliper, commonly used in accurate machining work, was utilized to minimize measurement errors. Three measurements were taken using the mean for the actual value. This data was then fed into a computer to make handling easier. A computer program is almost a necessity when a lot of points are to be measured. As Stafford (Stafford, 1971) points out, a computer program lessens (reduces) the time needed for calculating, leaving much more time for the selection and measurement of points.

The following sections contain discussions and tables on site locations in four test areas located in Muskegon County. (See Figure 2.) The data in brackets relate to sites where large errors occur. The bracketed values are put in mainly to demonstrate the magnitude of errors that can arise, and to indicate the limits and pitfalls inherent in this type of work. The letters NS before a year in a table indicate there was no stereo coverage for that year, but the values are still published to demonstrate the importance of stereo parallax as an element of interpretation. In many cases the calculation of rates in the non-stereo year will be omitted. A positive value of recession means recession of the bluff line, toe line, water

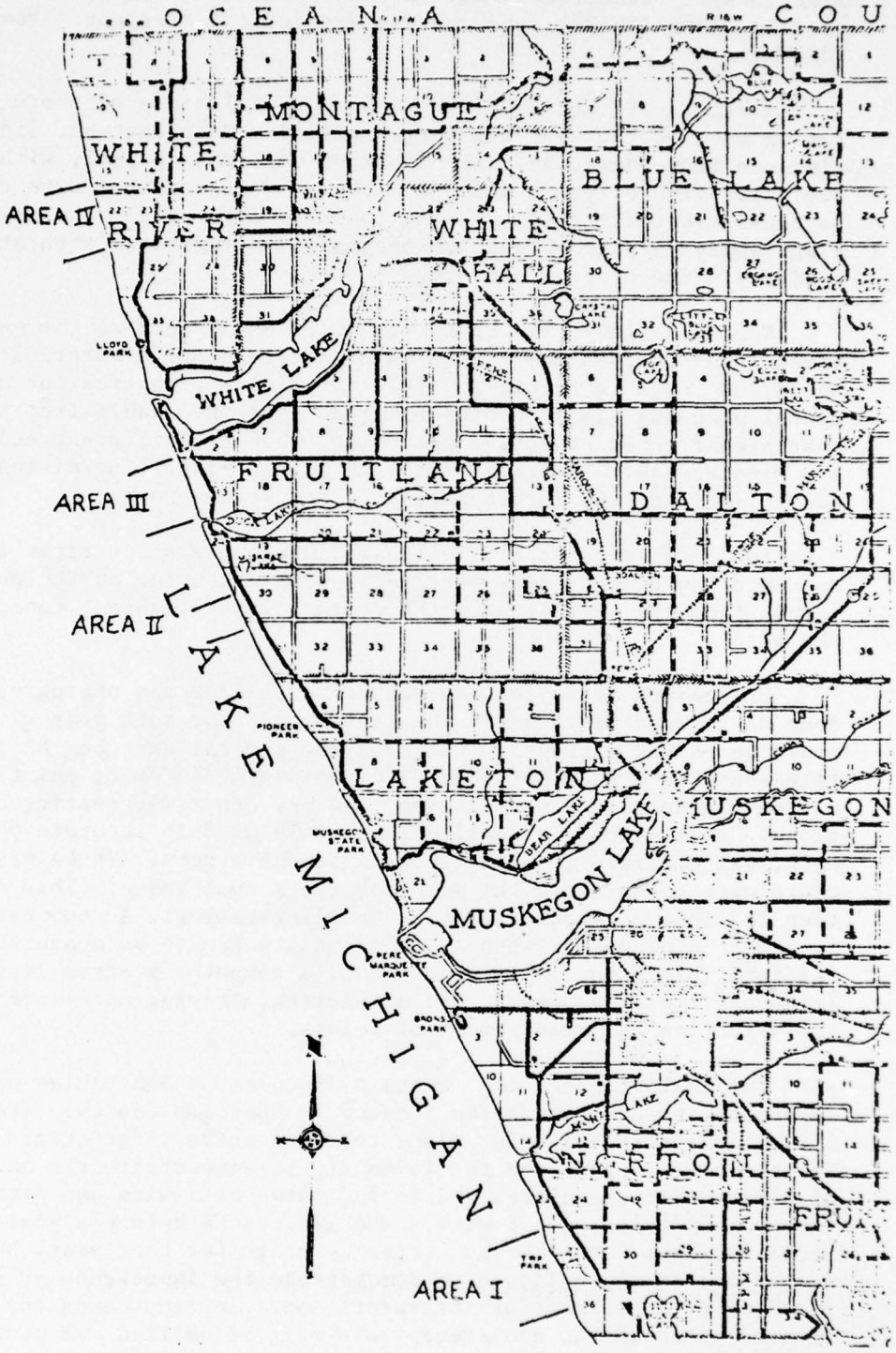



FIGURE 2. Location of test areas in Muskegon County

line, or bar line. Negative values indicate accretion or motion lakeward, for the bluff line, toe line, water line, or bar line.

Generalized profile sketches were made for most sites and years of coverage. They were sketched from the stereo photographs with the intent of showing the general features of the coast. These sketches are not to scale in either the vertical or horizontal direction and generally are very exaggerated in the vertical direction, as is usual for stereo images.

## ERRORS

Aerial photographs are not planimetric maps; thus the possibility of distortions must always be kept in mind if accurate measurements are to be obtained.

Critical errors in photographs are due to relief displacement, tilt error, measurement error, and interpretation error. The first two errors are expressed in non-linear scale variations in the image. Measurement errors involve the precision of the measuring tool. Interpretation errors vary with the quality of the photographs, their date and scale, and the skills of the interpreter. Methods were incorporated to reduce errors caused by these problems.

### Measurement Errors

The most probable value for a distance measured several times is the mean value. For this study each photograph distance was measured three times. The measuring tool was a six-inch dial caliper device with calibrations to .001 inch or .000083 feet. Obviously, this kind of precision can not be expected. If an optimistic precision of ± .002 inches is assumed, the equivalent ground distance for a 1:20,000 image scale would be 3.33 feet, or 1.66 feet for a 1:10,000 image scale. As Istvan (Istvan, 1974) points out, larger scale images will have a distinct advantage with regard to measurement precision. The degree of accuracy desired will always have to be weighted against the added costs of flying larger scale images as well as the extra processing involved in bringing older coverage to larger scales. Ten typical photograph distances were measured using the methods outlined earlier. The average standard deviation was found to be equivalent to 0.259 feet on the ground using a photographic scale of 1:20,000. Once a distance is identified, measurement errors will not cause much trouble. However, as will be discussed later, selection of the bluff line and toe line points is by no means a straightforward problem in many cases.

### Relief Displacement Error

On any photograph, image displacement will occur due to topographic relief. The magnitude of displacement will vary with the amount of relief, (elevation) of the place, and distance away from the nadir of the photograph. Formula 1 (Olson, 1972) expresses this relationship and was used to decide when displacement errors were to be corrected.

Formula 1. $$d = \frac{hr}{H}$$

d = photographic displacement due to relief
h = height of object
r = radial distance from nadir
H = height of the camera above base of object

If the scale is determined near the elevation of the bluff (Figure 1), no correction for scale or displacement is needed for the bluff line distance. However, the toe line, water line, and bar will be displaced from their correct position toward the nadir by a distance d. Another typical coastal form (Figure 3) requires a correction for the bluff line because of its elevation above the datum of the scale control points. This will cause displacement away from the nadir.

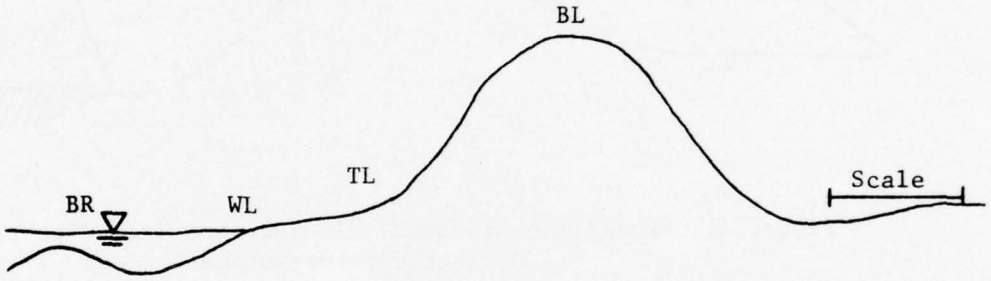



Figure 3. General profile shape, case 2.

Once displacement was calculated for any given point, its magnitude had to be corrected for the angular difference between the measurement direction and direction of radial displacement. For example, many cases were found where the bluff line followed the flight line. Radial displacement was then perpendicular to the measurement direction and caused no problem. In cases where the coast was not parallel to the flight line, the displacement distance BB' (Figure 4) was projected into the erosion measurement direction using the measured angle $\alpha$. The distance AB was used for the displacement correction instead of BB'.

Displacement corrections were made for all points where the error was considered critical (greater than one-foot ground distance). The elevation h (elevation difference between object and scale) was estimated from a topographic map giving only an estimated displacement correction. The parallax method of height determination would be a more accurate yet more time consuming way to obtain values for h.

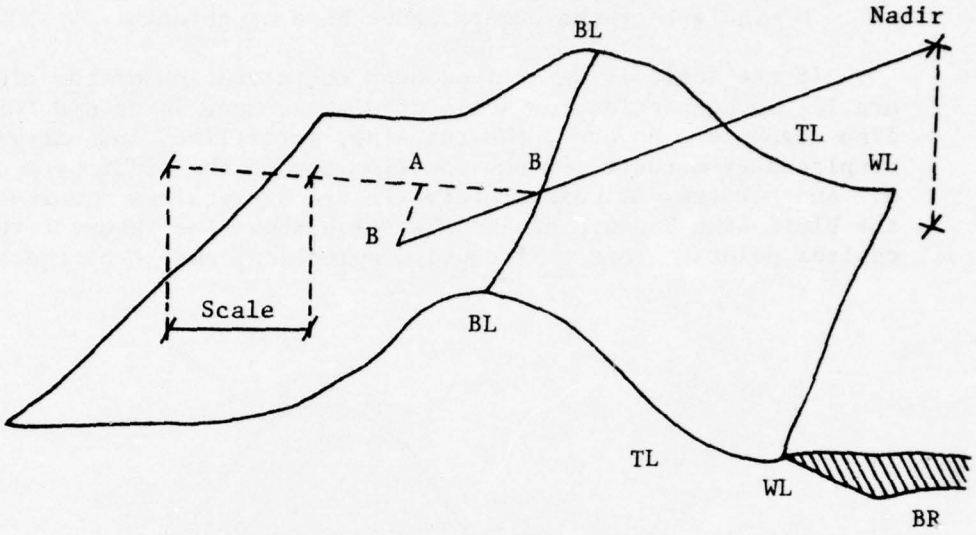



Figure 4. Projection of radial displacement into direction of recession measurement.

The displacement problem was especially critical for the 1974 images which had very large r distances, some greater than three inches with a flying height of 5000'. Displacement errors as great as 30 feet were calculated. These errors can be lessened by having the flight line of the photograph parallel to and centered along the coast. This is done by keeping measured distances as close to the principal point as possible, thus making r small, and by measuring scales at the same elevation as the bluff line or toe line.

## Tilt

All aerial photographs will have some degree of tilt away from a true vertical photograph. Tilt causes non-linear scale distortion across the image. It is generally an unknown; its magnitude will not be known or corrected for unless expensive first-order plotting devices or time-consuming methods are used. Tilt scale distortion is by no means restricted to any one direction. Tilt errors can be quite large depending on the quality of each year of coverage. Istvan (Istvan, 1974) calculated tilt errors to be much greater than relief displacement and measurement errors. Stafford (Stafford, 1971) and Wahls (Wahls, 1973) use rectified images as much as possible to minimize tilt error.

Steps in the methodology are intended to minimize this tilt error problem. It cannot be eliminated, however, unless very expensive methods are used. The best way to lessen tilt error is to determine scales for each site using a ground-measured distance; for example, the length of a driveway that shows clearly on all years of coverage. The scale control distance should be as close to the shore as possible, preferably less than 1000 feet away, and as parallel to the measurement direction as possible. Ground data with precision of less than one foot can be easily obtained using simple tape measuring techniques while checking the sites in the field. A scale measured near the site can alleviate errors introduced by using average scales, and avoids errors in scale determination which occur if topographic maps are used. For example, at several places in this study scale distances would have been in error by about 90 feet if topographic maps had been used. Ground measured distances for scale determination also give more freedom in site selection. Scale distortion due to tilt will be avoided except in the direction of measurement (Istvan, 1974). Thus, this method will minimize any tilt error as long as scale control points are as close to the shore as possible and measurements are made as parallel to the scale direction as possible. Note the scale variations that will occur on a photograph in Figure 8.

## Interpretation Errors

Interpretation errors appear to be the most critical, especially when working with photographs of 1:20,000 scale. They are given much less weight by previous workers in this field, however. Interpretation errors are generally errors of location of the bluff line, toe line, water line, and bar line, and will be referred to as location error. The question arises as to the location of the bluff line or toe line. There are several aspects to this location problem; the main ones arise from the edge gradient and the geometric shape of the coastal profile. The term "edge gradient" refers to the rate of change in emulsion density across the photograph. It is easy to define or locate an edge for measurement if it has a sharp edge gradient since there will be a large contrast difference in tone over a very short distance (see Figure 5a). With a poor edge gradient, the problem of location errors arises. Figure 5c demonstrates a poor edge gradient. It is hard to locate an edge for measurement if the tone contrast varies over a large distance. Figure 5b demonstrates a common case where there is a good edge gradient but little tone contrast making the edge difficult to locate and measure. Another case, not shown in Figure 5, would occur where both a poor edge gradient and little tone contrast exist. This was a common problem for toe line measurements. In some cases the edge gradient was so small that the toe line could not be located any more accurately than ±.012 inches on the photo, or ±20 feet on the ground at a scale of 1:20,000. Consider trying to locate the edge in Figure 5c. Also note that a photo distance error of only

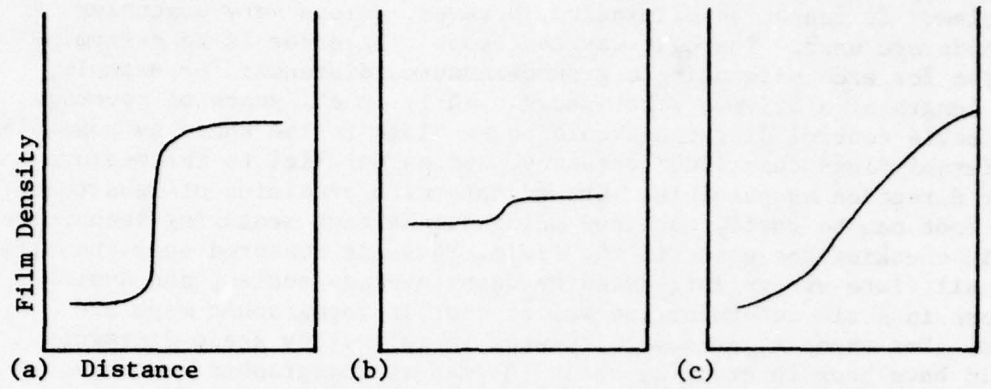



Figure 5. Three common edge gradients.
(a) Sharp edge gradient.
(b) Good edge gradient, but a small tone contrast.
(c) Poor edge gradient due to a gradual change in tone.

0.006 inch means ten feet on the ground with a 1:20,000 photo scale. Selecting the actual location of the bluff line, toe line, or bar line is not only a tone, edge gradient problem, but also a geometric problem. See Figure 6.

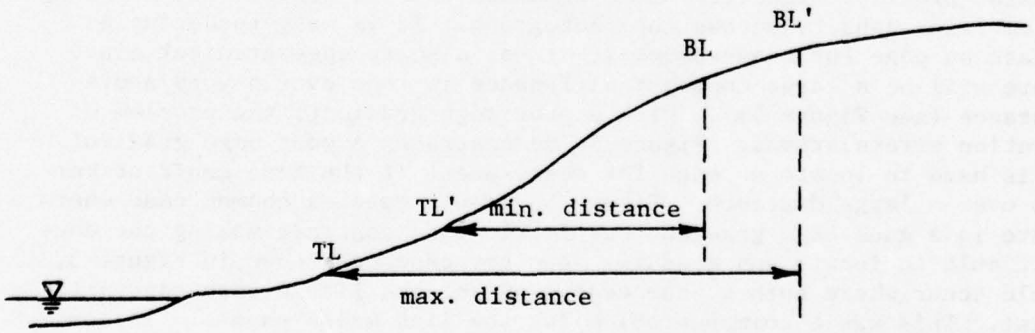



Figure 6. Profile shape ambiguities. Where is the bluff?

The question arises as to where the bluff line would be located, at BL or BL' or somewhere in between. Other location problems arise from yearly changes in beach profile which make standard selection difficult to determine. Also, the exact locale of the bluff lines can be blocked and shadowed by a thick tree canopy in summer images.

Limits to accuracy will mostly be due to tilt and relief displacement when very sharp edge gradients occur, for example, a measurement between the stripes down the center of a road and the edge of a building. This applies to most photo scale measurements. On the other hand, accuracy will be affected mostly by the edge gradient and the profile shape involved when measurements are made between a road, or house, and the bluff line or toe line. These may vary from year to year depending on the season, quality of images, and coastal changes.

The data gathered in this study indicate that, where fairly good edge gradients occur, an accuracy of no better than ±.006 inch in photo distance or ten feet ground distance at 1:20,000 scale can be expected for each measurement. When this ten-foot error is added to a possible ten-foot error in the same direction for the next year of coverage, an error of 20 feet can be assumed quite logically, if not optimistically. This location error will be added to scale, parallax, and tilt errors, which are minor compared to the location error, but are always present. Lesser edge gradients will make 20-foot errors seem small as is demonstrated in many values listed in the data section. Thus for any time interval, if a difference of 20 feet is measured, it can safely be said that the method will fail to give reliable information on real recession rates. A site with a recession rate of 30 feet between photo sets could be considered an active site if it had a fairly good edge gradient. For short time intervals, only sites with rapid erosion rates can yield reliable information within accuracy limitations. Over long time intervals, say 30 years, a recession of one foot per year could be determined for an active recession site because the 30-foot change or .012 inch photo distance is within the accuracy limitations. Given these accuracy limitations, the magnitude of any recession rate must always be considered with a variance in mind.

As an example, the bluff line at Site 12 was almost at the doorstep of a house on the bluff in all years of coverage, 1968, 1970, and 1974. It can be assumed that measurements from the control point to the bluff line should be the same ground distance for this site. Any variance will be due to location errors. The measured distances of the bluff line from the control point were 658, 627, and 655 for 1968, 1970, and 1974 respectively. The 1968 and 1974 images were of high quality, had good tonal contrast, and the shape of the bluff was not ambiguous (see Figure 25). In the 1970 image the bluff line was hard to pick out, as was typical in many other cases. The differences of 28 to 31 feet between the 1970 and the 1968 or 1974 data gives an idea of the magnitude of location errors.

## Methods to Lessen Errors

Some important criteria for selecting scale control points and site locations are listed below. Most are required to minimize errors, but others are suggested to avoid common pitfalls.

1. Select scale control points as close to the shore as possible.

2. The scale control line should be parallel or close to parallel to the direction in which bluff line measurements will be made. This means perpendicular to the coast.

3. The elevation of scale control points should be close to the elevation of the coastal area.

4. Each control point should be a distinct, permanent geographic location.

5. Each control point must be clearly visible in each year of coverage.

6. Good stereo coverage for each site is essential.

7. Selected controls should not vary with the seasons. For example, many times distinct controls in a spring photo will be covered with foliage in summer images.

8. Each site should be located near the center of at least one photo for each year of coverage.

9. Scale control points should be selected that are easily accessible and close enough for quick measurement, ideally no greater than 500 feet. Driveways are commonly the best.

10. Measure to the center of roads since they are more permanent than shoulders.

AREA I

Sites 1 through 3 are located in southern Muskegon County in Section 25, T.9 N., R.17 W. (see Figure 7). This section of the coast is classified as Warren Dune shoretype (Humphrys, Horner, Rogers, 1958). The bluff material consists of sand over clay and occasional sandstone outcrops in heavy clay. Dunes are composed of medium sand and range from 30 to 50 feet in height. Ground measurements for scale were made at five locations in this area in order to compare their usefulness with that of average scales or scales from topographic maps. As can be seen in Figure 8, rather large errors would occur if average scales were used. As was pointed out in the measurement error section, large errors would also be introduced if topographic maps were used. For example, ground distance at Site 1 was measured at 1013.25 feet using a cubitape; if the topographic maps were used, the distance would be 1187 feet.

The Site 1 measurement was made on a blowout dune. The distance was measured in from Lake Harbor Road at a right angle to the blowout end, bluff line, toe line, water line, and bar. For this special case the blowout end is listed under the bluff line column in Table 1. The toe line column lists the bluff line, while the rest are listed properly. The end of the blowout was estimated from a topographic map to be 160 feet above the section of land used for scale determination. Therefore, large relief displacement corrections were needed. In the 1970 image the blowout end was displaced 31.9 feet.

Site 2 is a bluff just north of the outlet of Little Black Creek. This explains the very wide beach as indicated in Table 1. In 1938, the entire bluff was tree covered and there was a large foredune. By 1968 all the vegetation was gone and there was no foredune. Generalized profiles are shown in Figures 9 through 11. A typical problem encountered with the 1938 and 1970 images was determining the location of the bluff line due to the thick tree canopy. Also note that the 1962 image had no stereo coverage, without which the bluff line and usually the toe line cannot be measured. The numbers for 1962 are given to demonstrate the magnitude of errors involved and are not intended as reliable values.

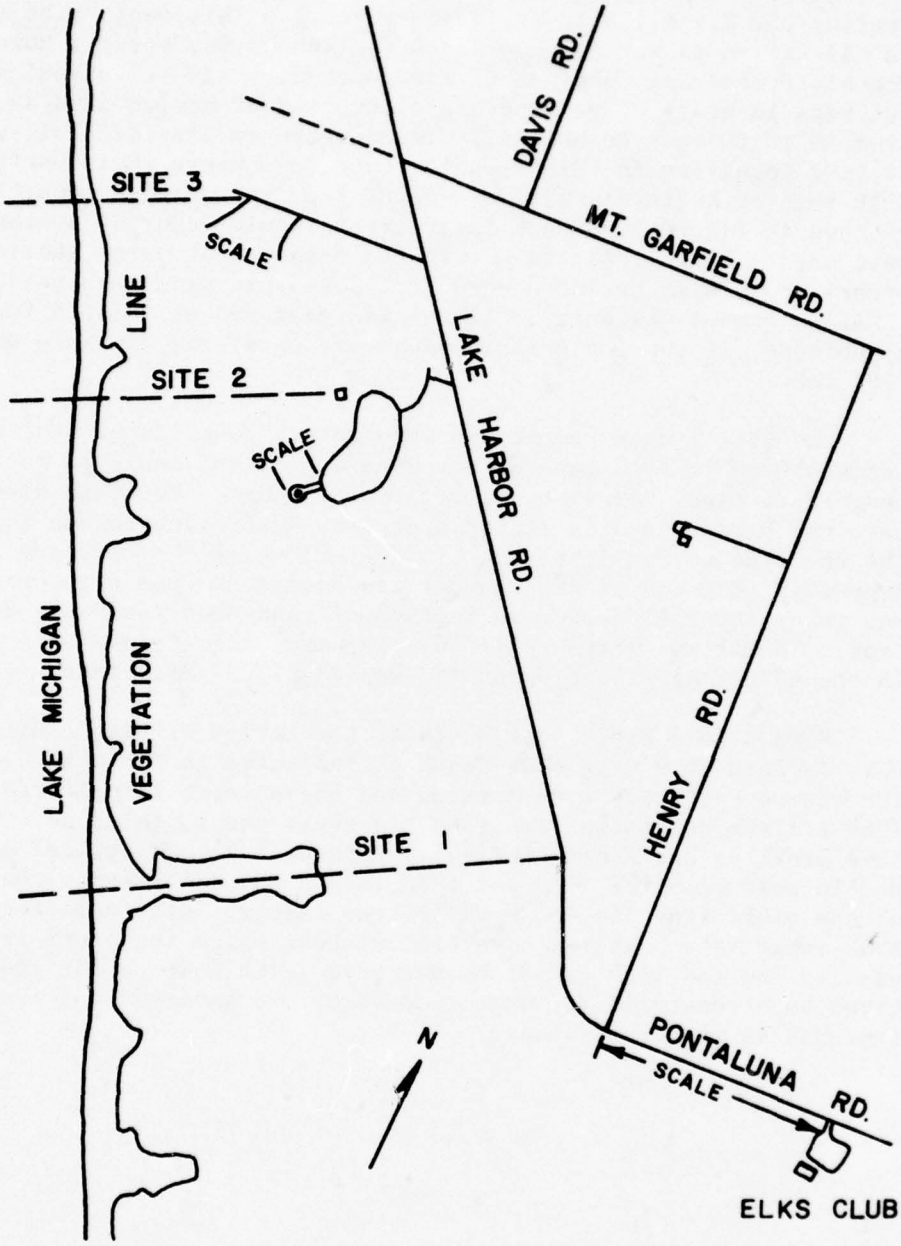



Figure 7. Location of sites in Area I. Section 25, T.9 N., R.17 W., Muskegon County, Michigan.

TABLE 1. Erosion Data for Area I. DBL, DTL, DWL, and DBR are in feet as are the bar distance, profile width, and beach width. RBL, RTL, and RWL are in feet/year.

| | Year | Scale | DBL | RBL | DTL | RTL | DWL | RWL | DBR | Bar Distance From Shore | Profile Width | Beach Width |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 1 | 1938 | 21403 | | | | | | | | 114.3 | 1635 | 135.7 |
| | | | 26.3 | 1.1 | 81 | 3.4 | 107.5 | 4.5 | 198 | | | |
| NS* | 1962 | 21782 | | | | | | | | 418 | 1580 | 109.4 |
| | | | 21 | 3.5 | 91 | 15.2 | 97 | 16.2 | 385 | | | |
| | 1968 | 20168 | | | | | | | | 130 | 1611.8 | 104 |
| | | | -1 | -.5 | 33 | 16.5 | 56.9 | 28.5 | 48 | | | |
| | 1970 | 21144 | | | | | | | | 84 | 1476 | 8 |
| | TOTAL | | 46 | 1.4 | 205 | 6.4 | 256 | 8.0 | | | | |
| Site 2 | 1938 | 21000 | | | | | | | | 116 | 96 | 235 |
| | | | 49 | 2.0 | --- | --- | 194 | 8.0 | 47 | | | |
| NS | 1962 | 19600 | | | | | | | | 263 | ---- | --- |
| | | | 20 | 3.3 | --- | --- | -65 | -10.8 | 87 | | | |
| | 1968 | 19750 | | | | | | | | 111 | 115 | 156 |
| | | | [-48] | [-24.0] | --- | --- | 68 | 34 | 45 | | | |
| | 1970 | 21250 | | | | | | | | | | |
| | TOTAL | '38-'68 | 48 | 1.6 | 23 | .71 | 129 | 4.3 | | | | |
| Site 3 | 1938 | 21146 | | | | | | | | 165 | 39 | 161 |
| | | | 42.9 | 1.8 | 57.8 | 2.4 | 102 | 4.3 | -19.5 | | | |
| NS | 1962 | 19721 | | | | | | | | 297 | 23 | 117 |
| | | | 29 | 4.8 | [-56] | --- | 140 | 4.7 | 122 | | | |
| | 1968 | 20233 | | | | | | | | 305 | 107 | 77 |
| | | | 6.8 | 1.7 | [-54] | [-13.0] | 167 | 41.9 | 186 | | | |
| | 1970 | | | | | | | | | 324 | 168 | 36 |
| | TOTAL | | 79 | 2.5 | 42 | 1.31 | 74 | 2.3 | | | | |

NS* indicates years with no stereo coverage.

See pages 2 and 3 for explanation of symbols.

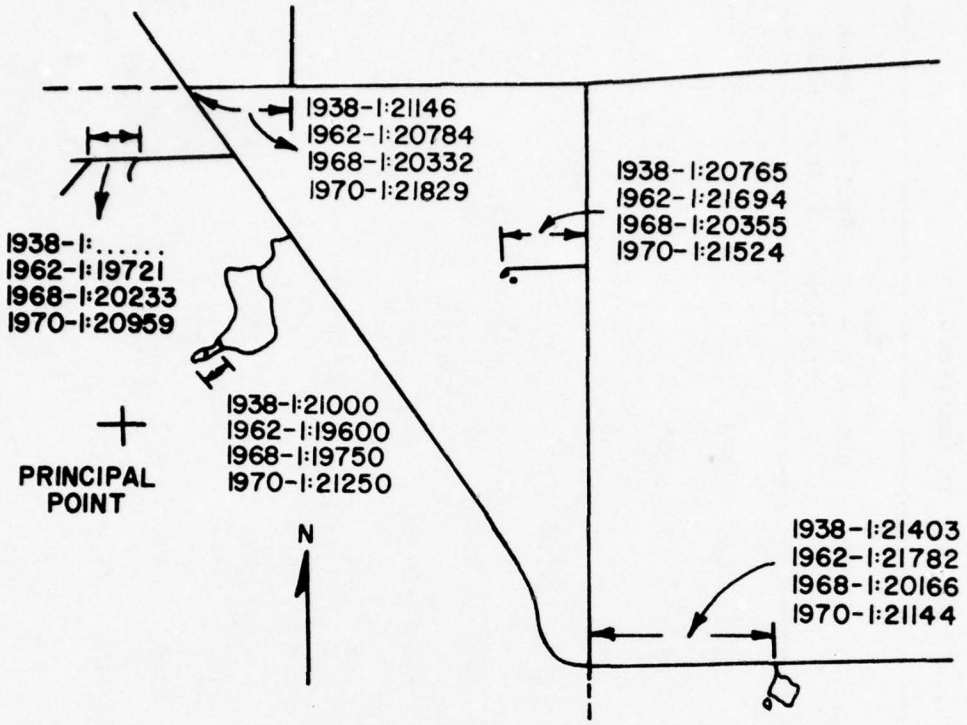



Figure 8. Scale variations in Area I.

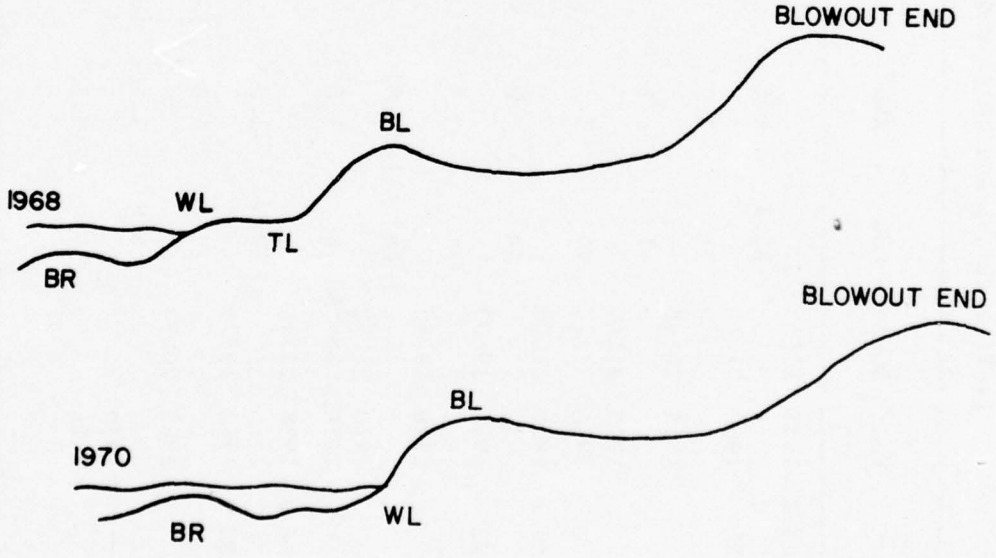



Figure 9. Generalized profiles, Site 1.

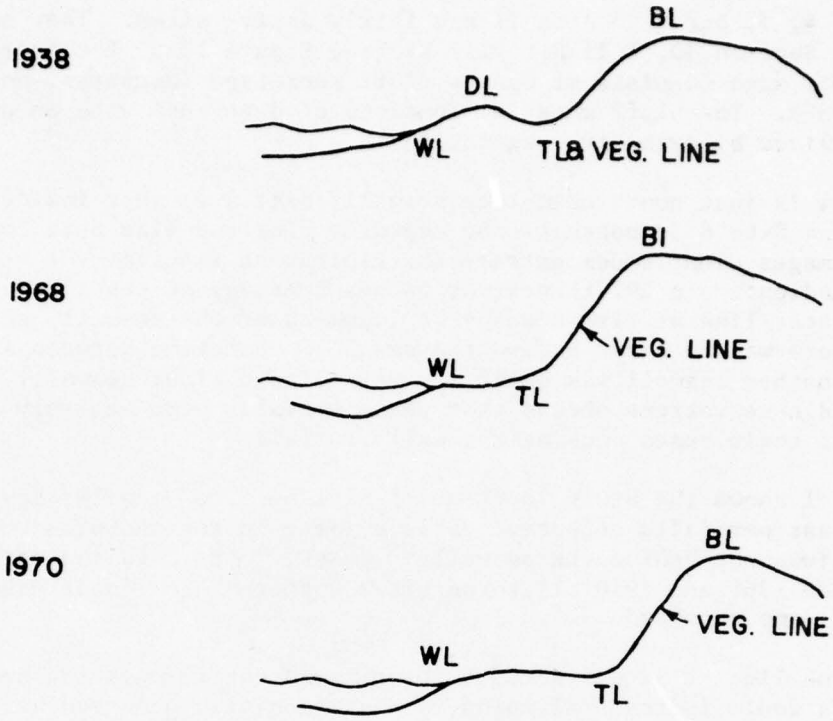



Figure 10. Generalized profiles, Site 2.

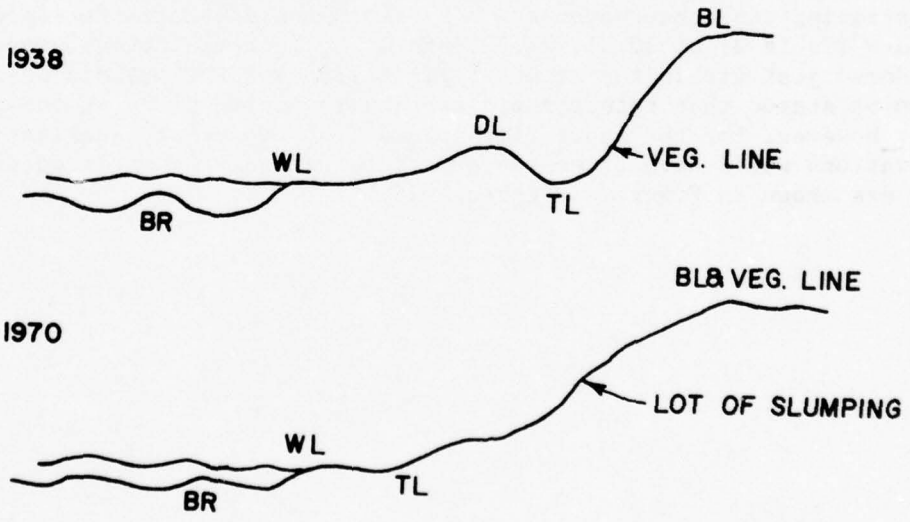



Figure 11. Generalized profiles, Site 3.

AREA II

Sites 4, 5, and 6 in Area II are fairly active sites. They are located in Section 30, T.11 N., R.17 W. (see Figure 12). The shoreline in this area consists of Ganges Bluff shoretype (Humphrys, Horner, Rogers, 1958). The bluff material consists of dune sand with an upland stabilized by extensive vegetation.

Site 4 is just south of a long seawall, Site 5 is just inside the seawall, and Site 6 is north of the seawall. The toe line data for the 1968 images clearly demonstrate the limitation imposed by the lack of edge gradient. In 1970 there was no beach at any of the sites. In 1968 the water line at Site 5 was just lakeward of the seawall, and in 1970 there was no water behind the seawall. Sometime between 1968 and 1970 another seawall was built lakeward of the older seawall. In 1975, field observations showed that these seawalls were severely undercut at their bases causing the walls to fail.

Photo 1 shows the bluff in front of Site 5. The seawalls have been at least partially effective as is evident in the photo where the coast juts out behind the seawalls. However, the data indicates that between 1968 and 1970 all three sites suffered erosion of essentially the same magnitude.

The toe line at Site 5 seems to have moved out to meet the seawall. This would indicate slumping, a condition also observed at other sites. It should be noted that measurements at Site 5 were difficult to take due to heavy vegetation.

The bar distance from shore varied greatly between 1968 and 1970, demonstrating rapid bar movement. The recession distances for Sites 4, 5, and 6 (Table 2) of 20.31, 27.73, and 11.85 feet respectively are considered just within the accuracy limitations of the methods used. It can be stated that rather rapid erosion is taking place at these sites; however, for the short time interval of two years, qualitative observations would have given the same information. Generalized profiles are shown in Figures 13 through 15.

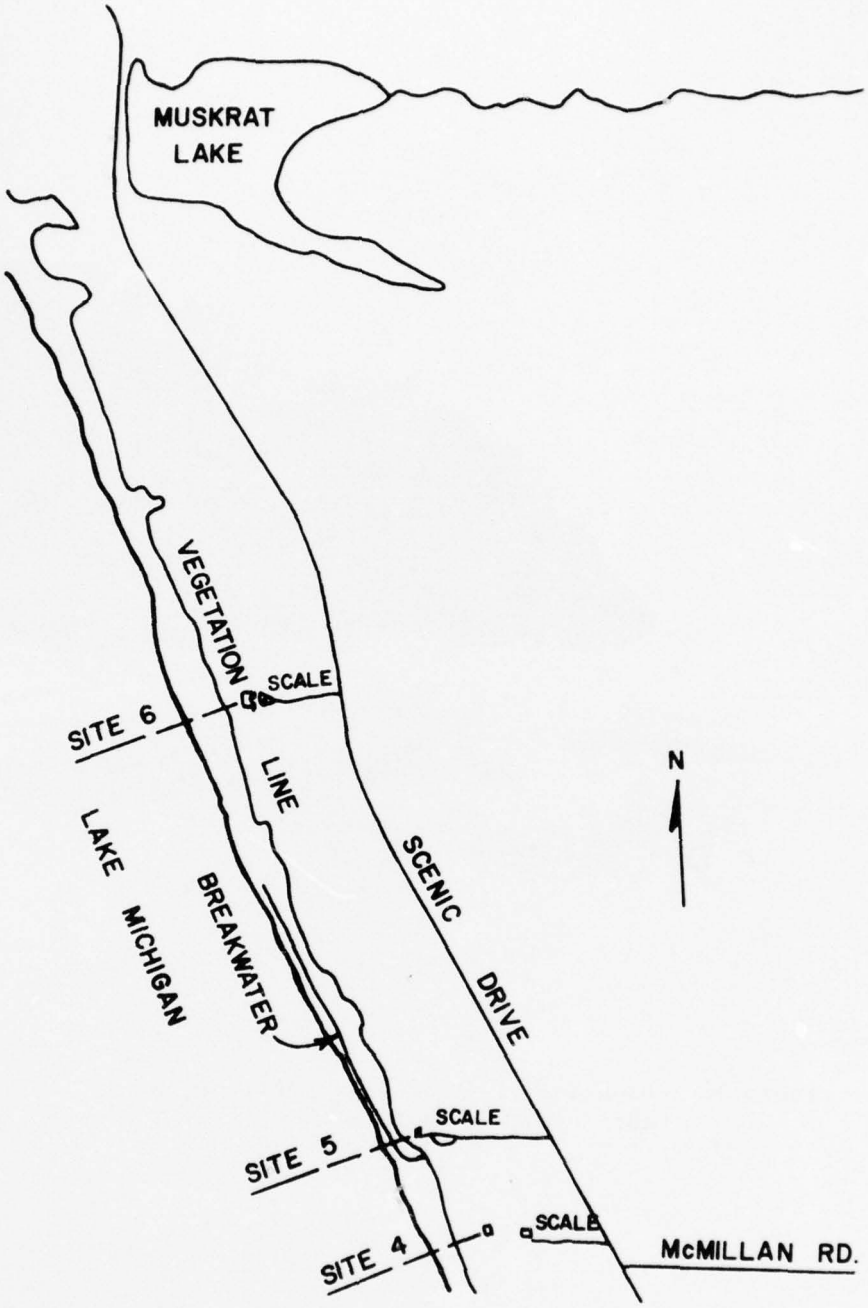



Figure 12. Location of sites in Area II. Section 30, T.11 N, R.17 W., Muskegon County, Michigan.



Photo 1. Beach and bluff at site 5 looking North.
Photo taken March 1975.

TABLE 2. Erosion Data for Area II. DBL, DTL, DWL, and DBR are in feet as are the bar distance, profile width, and beach width. RBL, RTL, and RWL are in feet/year.

| | Year | Scale | DBL | RBL | DTL | RTL | DWL | RWL | DBR | Bar Distance From Shore | Profile Width | Beach Width |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 4 | 1968 | 19741 | | | | | | | | 130.8 | 106 | 0 |
| | | | 20.3 | 10.2 | 2.4 | 1.2 | -7.6 | -3.8 | -142 | | | |
| | 1970 | | | | | | | | | 265.9 | 135 | --- |
| Site 5 | 1968 | | | | | | | | | 111 | [64] | [62] |
| | | | 27.8 | 13.9 | 12.7 | 6.3 | 74.3 | 37.1 | -125 | | | |
| | 1970 | 21041 | | | | | | | | 310.3 | 79 | 0 |
| Site 6 | 1968 | 21174 | | | | | | | | 262 | [60] | [73] |
| | | | 11.8 | 5.9 | 43.1 | 21.5 | 72 | 36 | 123 | | | |
| | | | | | | | | | | 211 | 74 | 0 |



See pages 2 and 3 for explanation of symbols.

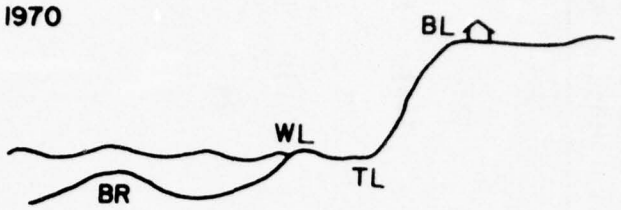
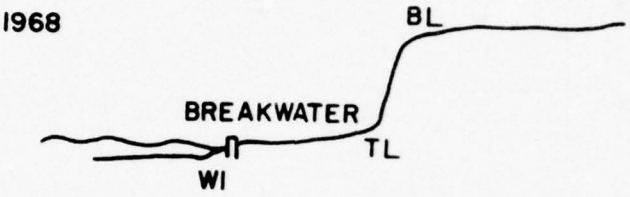



Figure 13. Generalized profile, Site 4.



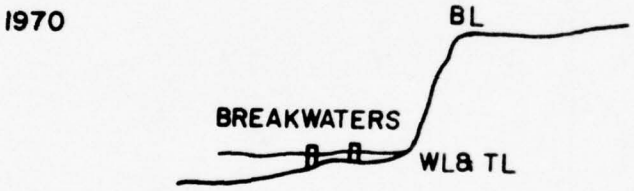




Figure 14. Generalized profiles, Site 5.

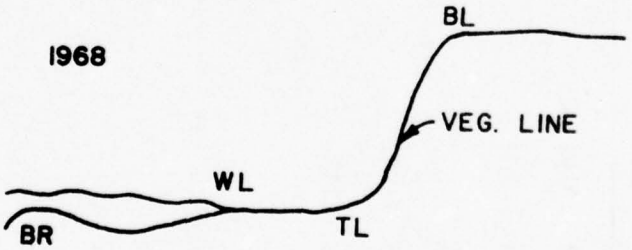



Figure 15. Generalized profile, Site 6.

AREA III

Sites 7, 8, 9, 10, and 11 are located between Duck Lake and White Lake (see Figure 16). Warren Dune shoretype is found along the coast (Humphrys, Horner, Rogers, 1958). In this area, bluffs are sand over clay and occasionally sandstone outcrops in heavy clay. Dunes are composed of medium sand.

Weaknesses occurred in data collection at these sites due to lack of stereo coverage for the 1970 data. The 1938 bluff lines were covered by a thick tree canopy except at Site 7. Due to the photo date of early May, the tree canopy did not block the bluff lines in the 1968 images. Toe lines again had poor edge gradients for the 1968 images.

Observations of the 1968 photographs indicate that the beach widths at Sites 8, 9, and 10 should be about the same, 10 being a little larger than 8, and 9 a little smaller than 8. However, calculated beach widths shown in Table 3 do not agree with values of 43, 59, and 35 feet for Sites 8, 9, and 10 respectively. This indicates the limitations in accuracy encountered in work with less than ideal edge gradients. Beach widths were calculated by subtracting the toe line distance from the water line measurements. It is felt that most of the location error is introduced in the toe line measurement, with less water line error introduced due to its better edge gradient. All sites in Area III experienced some erosion with an average 36-year loss of 24.4 feet or 0.68 feet per year. Between 1938 and 1968, recession distances for the bluff lines of Sites 7 through 11 averaged 18.34 total feet, or 0.65 feet per year. The maximum loss occurred at Site 10 with 0.934 feet per year and the minimum at Site 8 with 0.03 feet per year. Dr. Erwin Seibel (Seibel, 1972) conducted a similar study in the White Lake area and calculated an average recession rate of 1.9 feet per year from 1938 to 1970, or an average total distance of 61 feet for his Sites VII to XI. When an optimistic variance of $\pm$15 feet is considered for the recession distance in this report, a reliable rate for this data would be .11 to 1.12 feet per year. These figures are not so far from Seibel's keeping in mind that variances should also be applied to his values. It is also important to note that data in this study only goes to 1968, with 1969 being a year of higher lake levels that could affect the results. The differences could also indicate that methods and interpretation criteria varied. It is interesting that the 1938 to 1968 toe line measurements of this study average 54.8 feet recession or an average 1.82 feet per year compared to Seibel's bluff line average of 1.92 feet per year for the same area.

The data which could be obtained for this area seemed to indicate that the bars were about the same distance offshore in 1968 as in 1938. This in no way indicates that the bars have not moved, for in all likelihood they have moved many times.

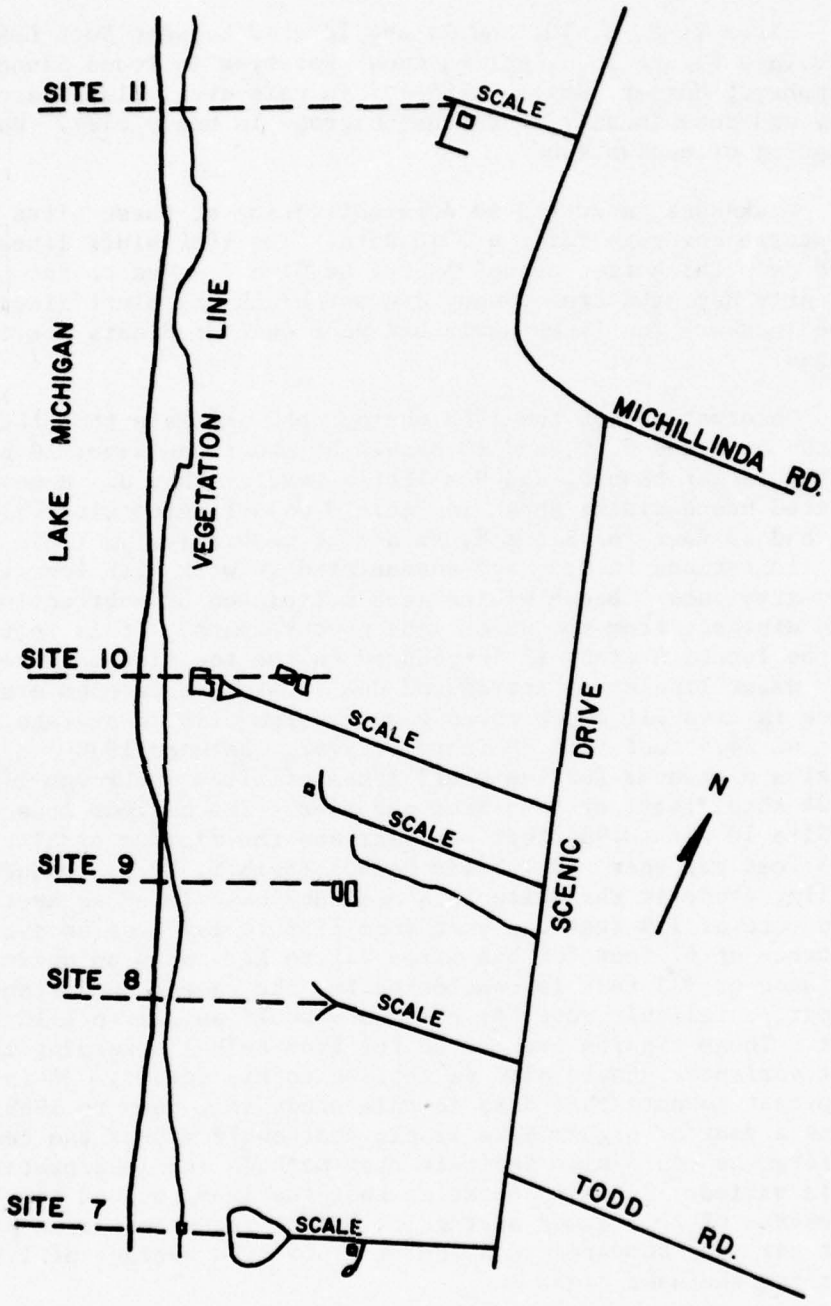



Figure 16. Location of sites in Area III, Section 13, T.11 N., R.18 W., between White Lake and Duck Lake, Muskegon County, Michigan.

By 1974 a breakwater had been placed just north of Site 8, around Sites 9 and 10. In the area of Site 9 large, active gullies are visible. At Site 10 no recession was measurable between 1968 and 1974. A 1975 field visit showed that Site 10 had extensive artificial slope stabilization. At Site 9 the bluff had receded some, possibly slumping and filling the breakwater as the toe line appears to have moved towards it (see Table 3 and Figure 19). In the 1974 images, waves reflecting from the Site 10 breakwater system were clearly visible 5800 feet from shore, but only in the peripheral portion of the large area of sun glint from the water. The waves were visible here because the wave surface geometry was correct for a specular reflection to reach the camera. Figures 17 through 21 show generalized profiles for sites in Area III.

TABLE 3. Erosion Data for Area III. DBL, DTL, DWL, and DBR are in feet as are the bar distance, profile width, and beach width. RBL, RTL, and RWL are in feet/year.

| | Year | Scale | DBL | RBL | DTL | RTL | DWL | RWL | DBR | Bar Distance From Shore | Profile Width | Beach Width |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 7 | 1938 | 21796 | | | | | | | | 221 | 137 | 92 |
| | | | 27.2 | .91 | 112.1 | 3.7 | 46.8 | 1.6 | 47 | | | |
| | 1968 | 21796 | | | | | | | | 220 | [52] | [121] |
| | | | | | | | 82.4 | 41.2 | | | | |
| NS* | 1970 | 20670 | 1.4 | .4 | -2.9 | -.5 | | | | --- | --- | --- |
| | | | | | | | -3.0 | -.7 | | | | |
| | 1974 | 10236 | | | | | | | | | | |
| | TOTAL | | 15.4 | .43 | 92.2 | 2.56 | | | | | | |
| Site 8 | 1938 | 21348 | | | | | | | | 257.8 | 99.7 | 62.3 |
| | | | .9 | .03 | 53 | 1.77 | 72.3 | 2.41 | -- | | | |
| | 1968 | 20687 | | | | | | | | --- | 47.9 | 42.7 |
| NS | 1970 | 21470 | 5.8 | 1.0 | [-47] | [-7.9] | -4.9 | -.8 | | | | |
| | 1974 | 9850 | | | | | | | | | 101.3 | 0 |
| | TOTAL | | 6 | .16 | 5.0 | .13 | 67 | 1.8 | | | | |
| Site 9 | 1938 | 21533 | | | | | | | | 245.7 | 61.0 | [102] |
| | | | 18.9 | .6 | 29.7 | .99 | 66.9 | 2.23 | -50.8 | | | |
| | 1968 | 20434 | | | | | | | | 267.4 | 50.0 | 59.6 |
| | | | 1.9 | .9 | 3.8 | 1.9 | 36.6 | 18.3 | -254 | | | |
| NS | 1970 | 21487 | | | | | | | | 558.6 | 48 | 26 |
| | | | 16.4 | 4.1 | -29.4 | -7.4 | -2.5 | -.64 | | | | |
| | 1974 | 9852 | | | | | | | | --- | 94 | 0 |
| | TOTAL | | 37 | 1.06 | 4.0 | .11 | 106 | 2.94 | | | | |

NS* indicates years with no stereo coverage.

See pages 2 and 3 for explanation of symbols.

TABLE 3 (continued)

| | Year | Scale | DBL | RBL | DTL | RTL | DWL | RWL | DBR | Bar Distance From Shore | Profile Width | Beach Width |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 10 | 1938 | 21184 | | | | | | | | 263.9 | 76 | 73 |
| | | | 28.34 | .94 | 41.0 | 1.37 | 79 | 2.63 | 80.2 | | | |
| | 1968 | 20434 | | | | | | | | 262.2 | 63.8 | 35 |
| | | | [-44] | [-22] | | | 2.3 | 1.2 | 79.4 | | | |
| NS | 1970 | 21425 | 0 | 0 | -44.6 | -7.4 | | | | | | |
| | | | | | | | -12.1 | -3.0 | | | | |
| | 1974 | 9852 | | | | | | | | --- | 108 | 0 |
| | TOTAL | | 28.0 | .77 | -4.0 | -.11 | 69.0 | 1.91 | | | | |
| Site 11 | 1938 | 20987 | | | | | | | | 232.6 | 190 | 90.9 |
| | | | 22.4 | .75 | 59 | 1.97 | 86.6 | 2.89 | 97 | | | |
| | 1968 | 19905 | | | | | | | | 222.3 | 153.6 | 63 |
| | | | | | | | [-22.7] | | 0 | | | |
| NS | 1970 | 20900 | 12.0 | 2.0 | [-85] | [-14] | | | | 200.3 | 78.4 | 34.8 |
| | 1974 | 9894 | | | | | | | | --- | 260.5 | 51.8 |
| | TOTAL | | 34 | .95 | -37.0 | -1.0 | 3.0 | .08 | | | | |

See pages 2 and 3 for explanation of symbols.

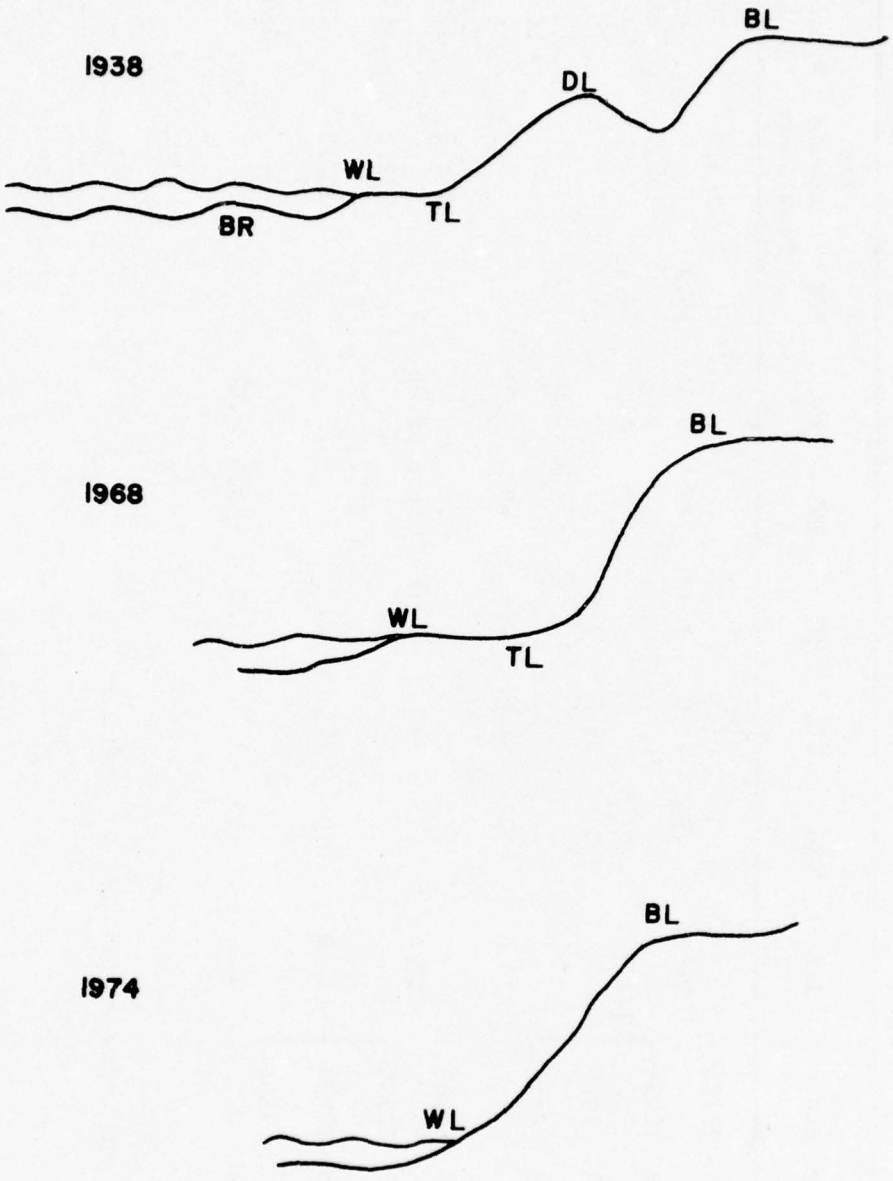



Figure 17. Generalized profiles, Site 7.

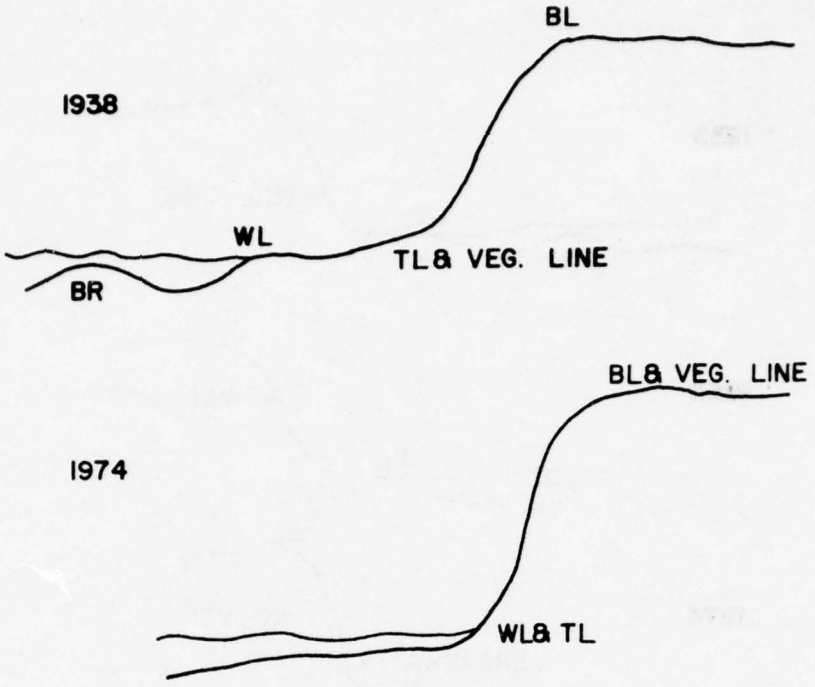



Figure 18. Generalized profiles, Site 8.

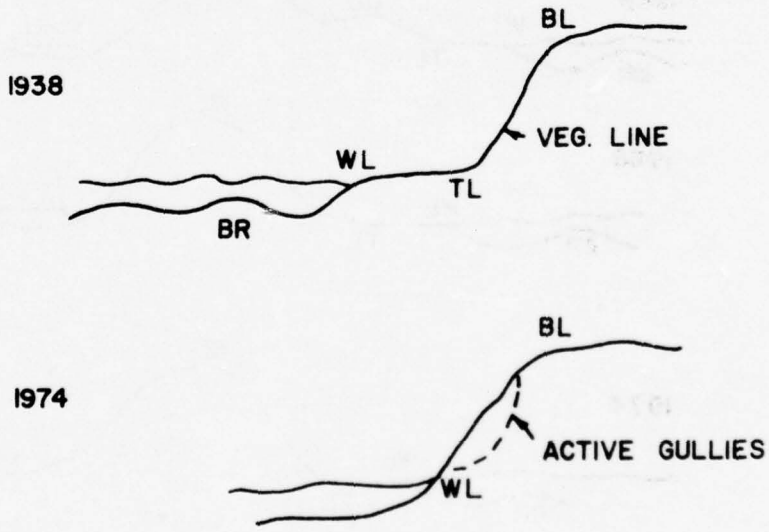



Figure 19. Generalized profiles, Site 9.

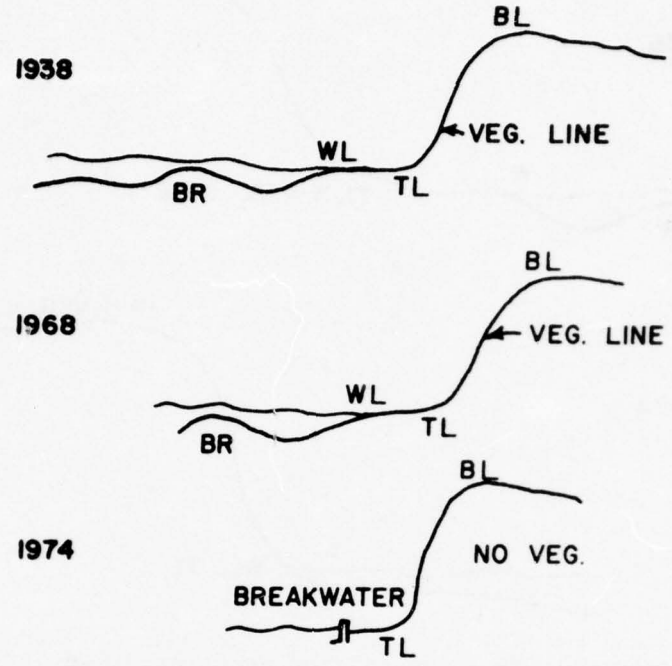



Figure 20. Generalized profiles, Site 10.

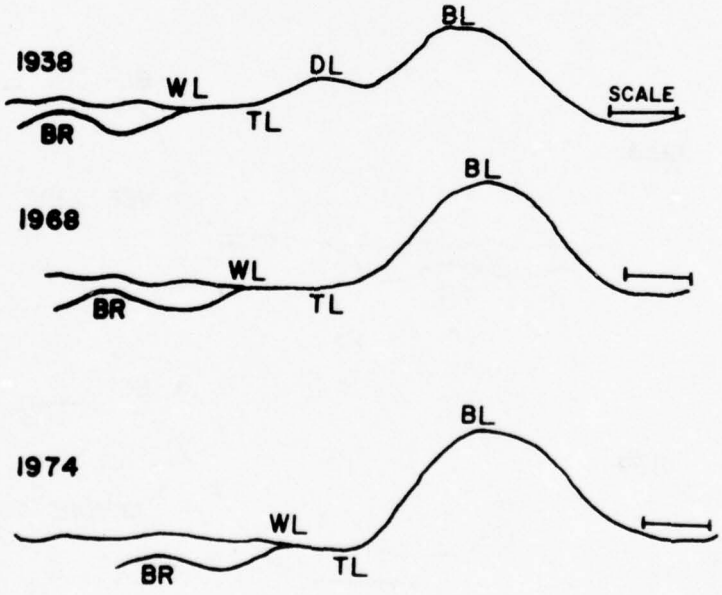



Figure 21. Generalized profiles, Site 11.

AREA IV

This area is located in Northern Muskegon County (see Figure 22). Site 12 is on the section line between Sections 22 and 27, T.12 N., R.18 W., and Sites 13 and 14 are on the section line between Sections 10 and 15, T.12 N., R.18 W. The northern-most section of the coastline is classified as Warren Dune shoretype (Humphrys, Horner, Rogers, 1958). The bluff material consists of medium sand over clay, with occasional sandstone outcrops in heavy clay. The southern section is classified as Montague Bluff shoretype. The lower portion of bluff consists of clay till with occasional sandstone slabs. The upper portion is stratified sand and silt. Sandy shorelines generally are not straight, but rather have a sinuous, rhythmic shape which may migrate along the coast. Dolan and Vincent refer to this crescentic nature of sandy coasts as sand waves (Dolan and Vincent, 1973). Comparison of the 1968, 1970, and 1974 photographs indicated that a sand wave was in the area of Site 12 (see Photo 2). Table 5 gives the wavelength and motions of the maximum and minimum amplitude parts of the sand wave. The Dolan and Vincent article (Dolan and Vincent, 1973) mentions sand wave wavelengths ranging from 490 to 3300 feet with most between 1600 and 1970 feet. This implies that the Site 12 sand wave is rather small with wavelengths of 1069, 883, and 884 feet for the years 1968, 1970, and 1974 respectively (see Table 5). Because the maximum amplitude has moved a total of 191 feet toward Site 12 from the north, the beach width should be larger in each year of coverage. By looking at Table 4, this is not observed to be the case, even though in 1974 the peak amplitude had moved to just north of Site 12. The problem involves errors in calculating beach widths. Beach widths were calculated by subtracting the toe line distance from the water line distance. Large errors were created by the lack of edge gradients at the toe lines, especially in the 1968 case. This problem can be avoided by looking at the entire dry profile, that is, the bluff line to the water line distance. The dry profile width is 247, 319, and 300 feet for the years 1968, 1970, and 1974 respectively. The 1968 value is much smaller than the 1970 and 1974 values, as it should be. However, the 1970 value is still larger than the 1974 value even though the peak amplitude of the sand wave is near the site. When the 1970 beach width is corrected by 28 feet, the assumed error in the bluff line distance (see ERRORS section, pages 6-12), the 1970 value is 291, not 318 as calculated from the original data. The profile width at Site 12 had increased 53 feet even though, between the 1968 date of coverage and 1974, the lake level had increased by five feet (see Table 6). The bluff line had stayed at about the same location at Site 12, as indicated in the Interpretation Errors section (page 9). The lack of bluff recession due to sand wave saved a poorly located house on the bluff. In about 14 years the trough of the sand wave may have moved to Site 12, leaving the bluff more fully exposed to the full force of waves.

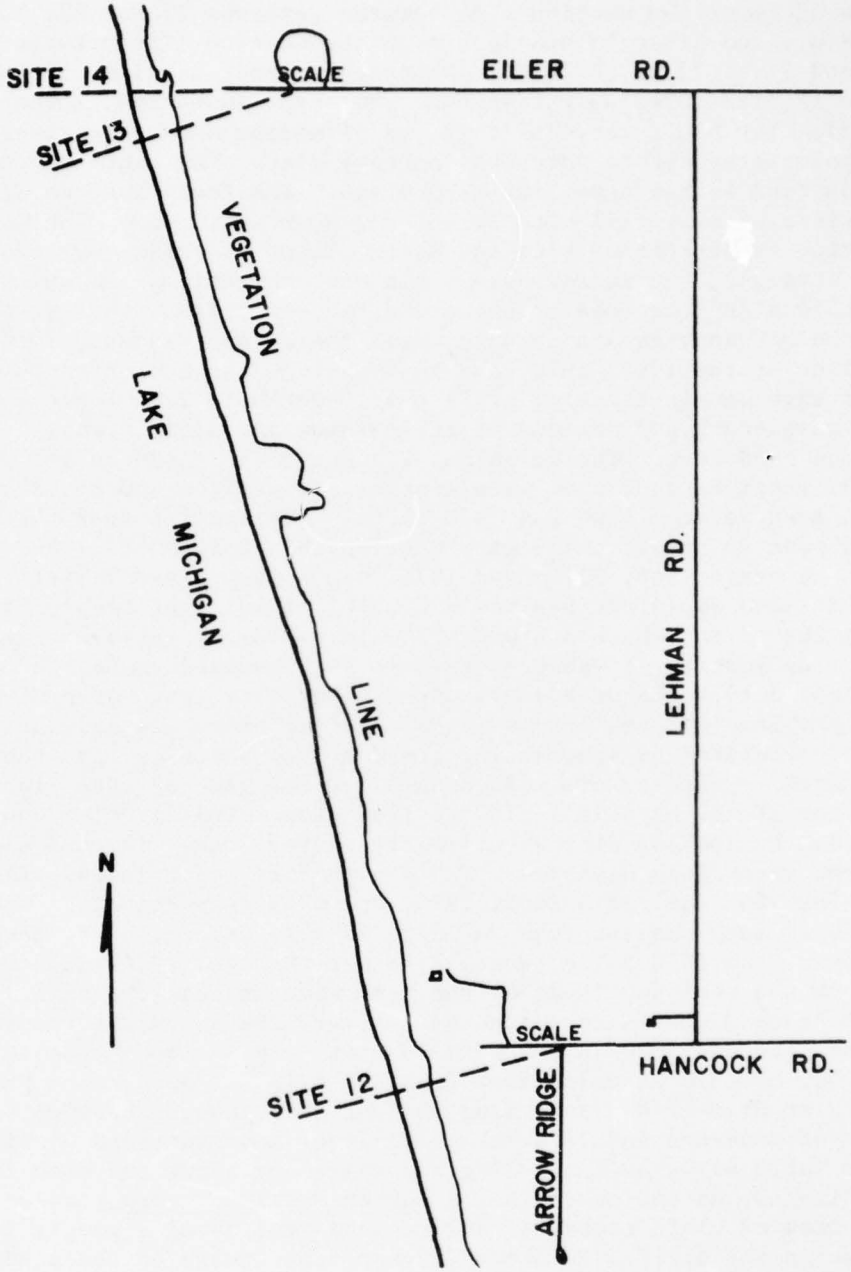



Figure 22. Location of sites in Area IV, Sections 22 and 27, T.12 N., R.18 W., northern Muskegon County, Michigan.

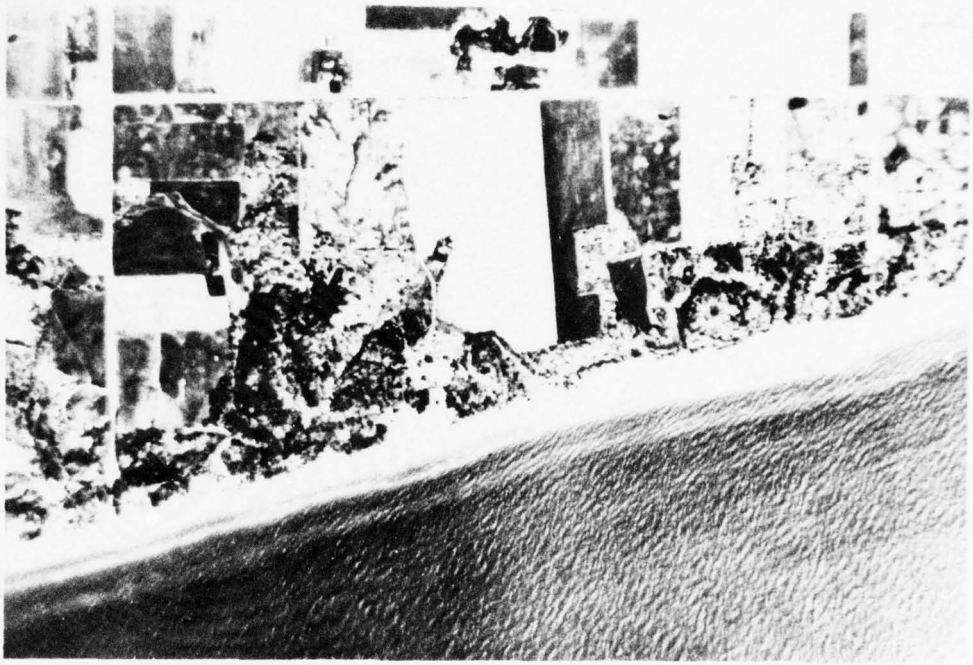


Photo 2. A copy of the 1968 aerial photo, BEI-2JJ-253, taken May 8, 1968. Refer to Figure 22 for locations of sites 12, 13, and 14. Site 12 is on the right. The sand wave can be seen around site 12. Note the lack of edge gradient at the toe line. Sites 13 and 14 are to the left of the photo. North is to the left.

TABLE 4. Erosion Data for Area IV. DBL, DTL, DWL, and DBR are in feet as are the bar distance, profile width, and beach width. RBL, RTL, and RWL are in feet/year.

| | Year | Scale | DBL | RBL | DTL | RTL | DWL | RWL | DBR | Bar Distance From Shore | Profile Width | Beach Width |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 12 | 1968 | 20000 | | | | | | | | 200 | 84 | 163 |
| | | | [31] | [15] | [27.1] | | 40.5 | 20 | -20 | | | |
| | 1970 | 21108 | | | | | | | | 179 | 141 | 176 |
| | | | [-28] | [-7] | -32 | -8 | -9 | -2.2 | 33.2 | | | |
| | 1974 | 9671 | | | | | | | | 204 | 146 | 154 |
| | TOTAL | | 3 | .5 | 59.1 | 9.1 | 49.2 | 8.2 | | | | |
| Site 13 | 1968 | 20416 | | | | | | | | 111 | 61 | 93 |
| | | | [40.7] | [20] | [38] | | 78 | 39 | 110 | | | |
| | 1970 | 19432 | | | | | | | | 79 | 65 | 52 |
| | | | [-24] | [-6] | [-30] | | 22 | 5.6 | --- | | | |
| | 1974 | 9211 | | | | | | | | --- | 34 | 0 |
| | TOTAL | | 16.6 | 2.8 | 8.0 | 1.3 | 101 | 16.8 | | | | |
| Site 14 | 1968 | 20417 | | | | | | | | 107 | 122 | 98 |
| | | | [64] | [32] | [26] | 13.3 | 92 | 46 | 95 | | | |
| | 1970 | 19417 | | | | | | | | | 159.8 | 32 |
| | | | [-28] | [-7] | -31 | -9.8 | -7 | -1.7 | | | | |
| | 1974 | | | | | | | | | --- | 171 | 0 |
| | TOTAL | | 36.0 | 6.0 | -12.0 | -2.0 | 86.0 | 14.3 | | | | |

See pages 2 and 3 for explanation of symbols.

TABLE 5. Sand Wave Data*

| Year | λ (ft) | Δ Max. (ft) | R Max. (ft/yr) | Δ Min. (ft) | R Min. (ft/yr) |
|---|---|---|---|---|---|
| 1968 | 1069 | | | | |
| | | 50 | 25 | 236 | 118 |
| 1970 | 883 | | | | |
| | | 164 | 41 | 163 | 40 |
| 1974 | 884 | | | | |
| | | 191 | 31 | 399 | 66 |

* Sand wave data, λ = wavelength of sand wave (feet), Δ Max. is the distance the maximum amplitude has progressed southward along the coast in feet. R Max. is the rate in feet per year, and Δ Min. is the distance the minimum amplitude has moved along the coast in feet. R Min. is the rate in feet per year.

TABLE 6. Lake Levels for Dates of Photo Coverage

| Date | Lake Level (ft)* |
|---|---|
| 6-30-1938 | 577.6 |
| 6-13-1962 | 577.9 |
| 5-8-1968 | 578 |
| 6-1970 | 579.2 |
| 4-23-1974 | 583.2 |

* Elevation in feet above International Great Lakes datum (1955).

Sites 13 and 14 did not have the benefit of a sand wave for protection, and by 1974 had no beach at all. Site 14 was measured straight down the road from the control point. Site 13 was measured in a south-west direction from the control point to the top of a tall bluff just south of Site 14.

In the 1968 image, Site 14 had a good edge gradient and profile geometry for the bluff line measurement. However, there was no edge gradient for the toe line (see Photo 2). In 1970 the bluff line and toe line of Site 14 were very hard to determine due to trees and poor exposure of the light sand area. The 1974 image was good for both Sites 13 and 14, except for displacement errors which have been approximately corrected for. Also, the profile shape at Site 14 is very rounded making the selection of the bluff line very subjective. In 1968 the bluff line of Site 13 was difficult to determine, and the toe line impossible to determine, as on most 1968 images. The 1970 image showed good bluff and toe lines for Site 13.

It is possible to conclude from the data combined with photo and field observations that Sites 13 and 14 are active erosion sites. At Site 14 the bluff line was at the edge of a house in 1974. By 1975 the house was half off the bluff (see Photo 3). Site 13, by measurement and especially by photo observation, can be called an active erosion area, even though a structure was placed there between 1970 and 1974. There are groins along the entire section in the 1974 image. Generalized profiles are shown in Figures 23 through 25.



Photo 3. Beach and bluff at site 14, looking north. Photo taken March 1975.

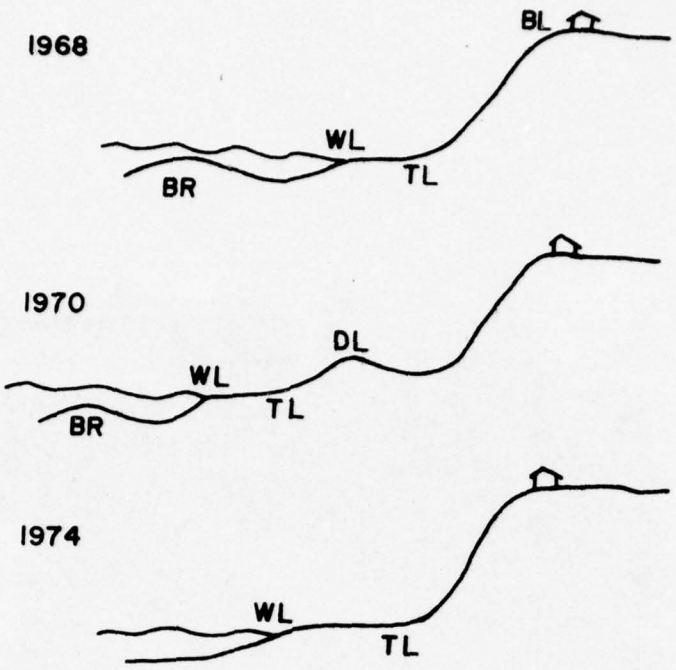



Figure 23. Generalized profiles, Site 12.




Figure 24. Generalized profile, Site 13.

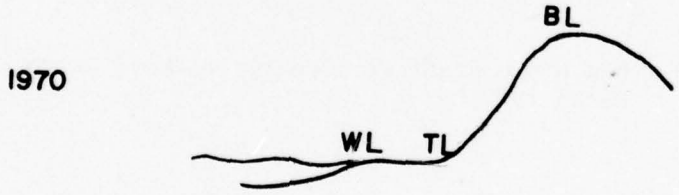



Figure 25. Generalized profile, Site 14.

## ANALYSIS OF METHODS AND DATA

Data showing large errors, those in brackets in Tables 1 through 4, correspond to location problems that were noted in the respective area sections. Location errors arose due to lack of stereo coverage, poor edge gradients, poor tone contrasts, rounded beach profiles, and dense foliage. Sites must be selected that avoid these problems if errors are to be minimized. Location errors were most common with toe line measurements, generally due to over exposure of the bright sandy beach area. Shape ambiguities were also common at toe lines, and poor toe line measurements commonly gave incorrect beach width data. It is felt that the time spent measuring toe lines is not worthwhile because of the frequency of these location errors. Bar line measurements indicated that the center of the first bar was generally about 200 feet from the water line, although distances ranged from 79 feet at Site 13 in 1970 to 558 feet at Site 9 in 1970.

The total recession rates for the bluff line, toe line, and water line are shown for each site in Figure 26. Note that each test area consists of different years of coverage so correlations between test areas should not be made. Lines drawn to connect rates within the same category are only for viewing ease. Because of the large separation between sites, these lines are not to be considered as intermediate values. There does, however, seem to be some correlation between bluff line, toe line, and water line recession rates for those sites located close to each other. For example, Sites 2 and 3, in Area I, were in close proximity, and the bluff line and toe line total recession rates had similar relative relationships, the bluff line rate being greater than the toe line rate (Figure 26). In test Area III, Sites 7 through 10 were close to each other. Relative relationships for the various recession rates were similar, with the bluff line rates generally being greater than the toe line rates. Sites 4 and 5, in Area III, were also close. The total bluff line and toe line rates had the same relative relationships, with the total bluff line greater than the toe line rate.

Not enough sites were measured to make broad correlations on coastal dynamics between sites, but it was not the intent of this study to do so. The purpose of this study was to demonstrate the kind of accuracy that can be obtained in recession measurements, which must be firmly established before correlations along stretches of coastline can be made. Even after a reliable method of measurement is developed, the non-linear nature of coastal processes in both time and space relationships must be dealt with. A random or uniform sampling program must be set up in order to give a representative recession rate along an entire stretch; widely spaced measurements cannot produce similar results. Site spacing may have to be as close as 100 feet before correlations along a stretch of beach can be made (Seibel, 1975). Coastal processes are perhaps even less linear in relation to time than in the spatial sense. Recession

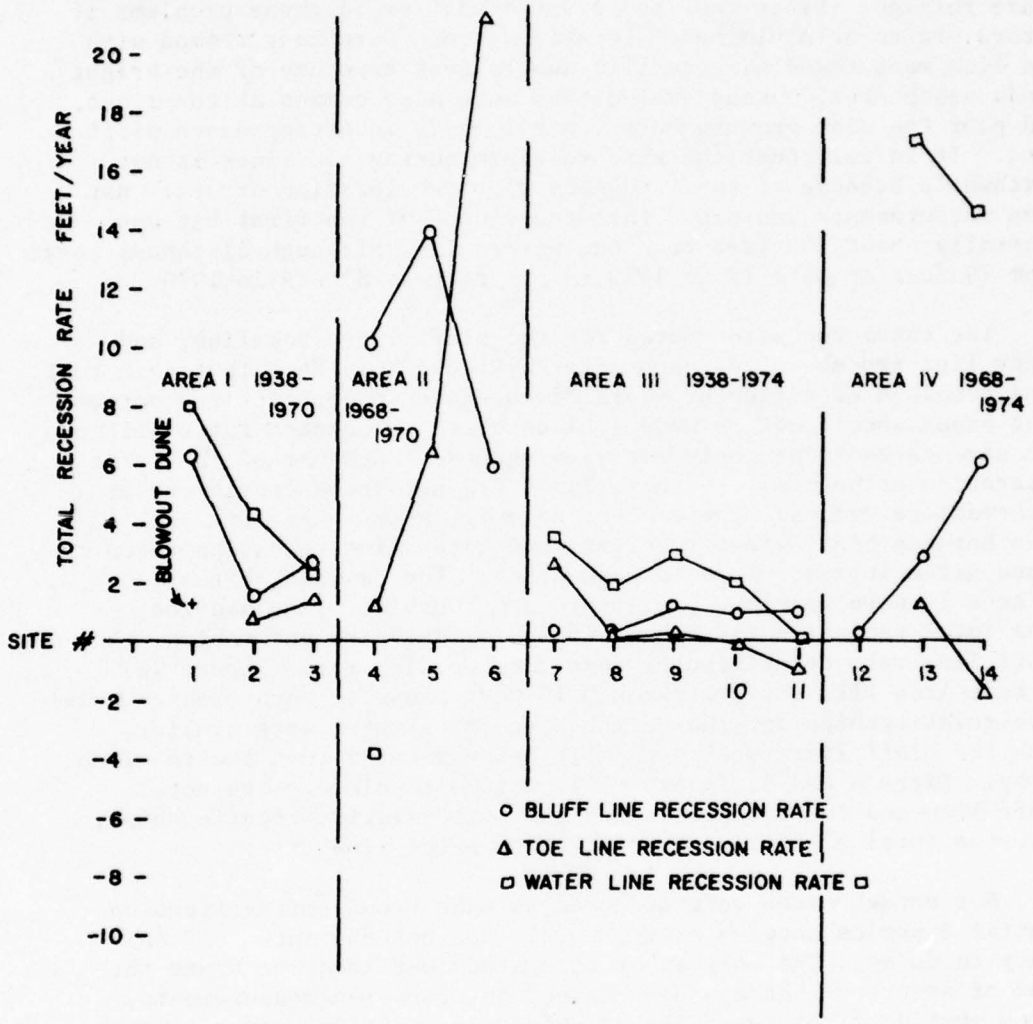



Figure 26. Total recession rates for all sites.

rates over long time intervals give only grand averages. However, due to the non-linear nature of coastal processes, it is very possible that only a few storms or a few years of high water could cause the greater part of the recession. Therefore, averaging over many years tends to mask the dynamic nature of coastal processes.

The methods used in this study can produce useful data for ideal sites, that is, sites with no location error problems and good scale control points. However, in determining recession rates for any given section of coast, an adequate number of ideal sites may not be found. A random or uniform sampling program will include many inferior sites and exclude many ideal sites. This creates a dilemma between measurement accuracy and practical sampling methods. Working only with ideal sites limits the total number of sites in any coastal stretch and biases data with cultural areas where increased erosion may be due to increased activity and vegetation damage. A good sampling scheme increases tilt and location errors which create poor data. The measurement of recession rates on sections of coast with no cultural features would also be extremely difficult in most cases.

## CONCLUSIONS

This study shows that the measurement of bluff recession rates is a rather challenging problem especially when using 1:20,000 scale images. The methods employed were designed to minimize measurement errors by using an accurate measuring instrument and by taking the mean value of three measurements. Tilt errors were minimized by using ground measured distances to determine photo scales near each site. Relief displacement errors were corrected for where needed, and measurements with location errors were noted. Even with these controls, errors were detected. Examples are the 28 and 21 foot variance in bluff line measurements at Site 12 (see pages 10-11), and the variances observed in beach widths at Sites 8 through 10 (see page 23). Location errors are considered the most critical because they could not be minimized, as were the other three major sources of error.

The degree of accuracy desired will always be weighed against added costs of larger scale images that are easier to interpret and measure. If images are being purchased, enlarged and rectified photography would be best for accuracy, but would be more costly and less readily available.

The most accurate methods for recession studies would require first order plotting instruments using advanced photogrammetric techniques. The costs involved here would by far outweigh any practical application of the information. If imagery is to be flown for work on coastal studies, it is recommended that it be at a scale of at least 1:10,000 and flown in early spring when foliage does not block the view. The line of flight should be parallel to the coast, placing the coast in the center of the photographs to minimize relief displacement and show plenty of land for good scale control points.

(cont fr R 1423A)

This report clearly indicates that recession rates cannot be quantified to the desired degree. Only "ball park" values of rates can be obtained under two possible situations using the methods outlined in this paper: (1) when a great deal of erosion occurs over a short period of time, or (2) when measurements are made over a long time interval. Indications of rapid recession over a short time interval can usually be detected by simple observation of the aerial photographs.

These two types of measurements are beneficial to the study of recession rates which can contribute valuable information to all agencies or interested parties: for example, local municipalities who may define setback distances for the construction of homes and businesses.

REFERENCES


Brater, E. F. and Seibel, E., 1971. "An Engineering Study of Shore Erosion in the Lower Peninsula of Michigan," Submitted to Michigan Water Resources Commission.

Davis, Richard A., Seibel, E., and Fox, W. T., "Coastal Erosion in Eastern Lake Michigan--Causes and Effects," Proc. Conference of Great Lakes Research.

Davis, Richard A., "Systematic Beach Profile Study of Eastern Lake Michigan," 1971. Annual Status Report, Aug. 1971, Contract DACW72-70-C-0037, Dept. of the Army, Coastal Engineering Research Center, Washington, D.C.

Dolan, R. and Vincent, L., 1973. "Coastal Processes, High-Altitude Aerial Photographs Aid in Investigations," Photogrammetric Engineering, Vol. XXXIX, No. 3, p. 255.

Farrand, W. R., 1970. "Rate of Recession of the Lake Michigan Bluff Along the Ludington Pumped Storage Project," Submitted to EBASCO Services, Inc., Purchase Contract E-10052.

Gelinas, P. J. and Quigley, R. M., 1973. "The Influence of Geology on Erosion Rates Along the North Shore of Lake Erie," Proc. 16th Conference of Great Lakes Research.

Hands, Edward B., 1970. "A Geomorphic Map of Lake Michigan Shoreline," Great Lakes Research Center, U. S. Lake Summary, Detroit, Michigan.

Humphrys, C. R., Horner, R. N., and Rogers, J. H., 1958. "Shoretype Classification of Muskegon County, Michigan," Department of Resource Development, Agricultural Experiment Station, Michigan State University, East Lansing.

Istvan, Larry, 1974. "Shoreline Recession Rate Studies from Aerial Photography," ERIM, Ann Arbor, Michigan.

Olson, Charles E., Jr., 1972. "Elements of Photographic Interpretation," University of Michigan, Ann Arbor, Michigan.

Olson, Jerry S., 1958. "Lake Michigan Dune Development, Plants as Agents and Tools in Geomorphology," The Journal of Geology, Vol. 66, No. 4.

Olson, Jerry S., 1958. "Lake Michigan Dune Development, Lake-Level, Beach, and Dune Oscillations," The Journal of Geology, Vol. 66, No. 5.

Pincus, Howard J., "Recession of Great Lakes Shorelines," Department of Geology, Ohio State University, Columbus.

Seibel, Erwin, 1972. "Shore Erosion at Selected Sites Along Lakes Michigan and Huron," Department of Meteorology and Oceanography, Ann Arbor, Michigan.

**Stafford, Donald B., 1971.** "An Aerial Photographic Techniques for Beach Erosion Surveys in North Carolina," Technical Memorandum No. 36, U. S. Army Corps of Engineers, Coastal Engineering Research Center.

**Wahls, H. E., 1973.** "A Survey of North Carolina Beach Erosion by Air Photo Methods," Report No. 73-1, Project ERSD-464, Center for Marine and Coastal Studies, North Carolina State University, Raleigh, North Carolina.

**Map Used**

**Triennial Atlas and Plat Book** Muskegon County, Michigan, Rockford Map Publishers, Rockford, Illinois.

**USGS Topographic Maps:** Lake Harbor, Michigan and Montague, Michigan.

# APPENDIX I

## INDEX OF AERIAL IMAGERY FOR COASTAL AREAS OF MICHIGAN

How to Locate Photographs

Key to Index

Index Chart

In-State Agencies

Out-State Agencies

## How to Locate Photographs

To purchase aerial photographs for a specified area or date, find available photographs on the Index Chart and contact the main offices listed in the In-State and Out-State Agencies lists attached. Check the in-state offices of federal and state agency field offices, federal buildings, and city halls to view publicly held photographs of your area of interest.

This index should be considered incomplete. Some photographs are not listed and may be found in offices unknown to the author.

KEY TO INDEX

The numbers at the head of each column refer to agencies listed in the following sections. Photo scales could not be obtained in all cases; however, the key includes many of the most common scales and focal lengths to aid in expansion of this index.

Example of listing:

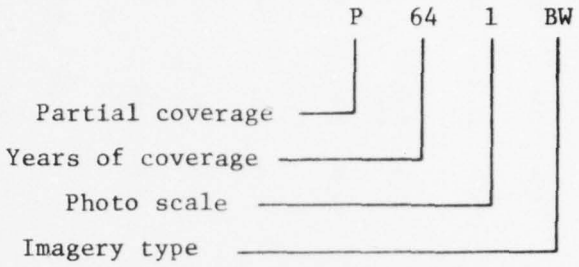



Photo - Index Key

Imagery type

BW - Black and white film
C - Color film
IR - Infrared film
CIR - Color infrared film
S - Scanner system
MS - Multi-spectral imagery

Photo Scale

a - 1:500
b - 1:6000
c - 1:9600
d - 1:10,000
e - 1:12,000
f - 1:15,000
g - 1:15,840
h - 1:17,000
i - 1:18,000
j - 1:19,000
k - 1:19,200
l - 1:20,000
m - 1:21,000
n - 1:23,000
o - 1:24,000
p - 1:25,000
q - 1:26,000
r - 1:27,000
s - 1:30,000
t - 1:32,000
u - 1:34,000
v - 1:40,000
w - 1:46,000
x - 1:50,000
y - 1:58,000
z - 1:60,000
aa - 1:69,000
ab - 1:72,000
ac - 1:118,000
ad - 1:120,000

| COUNTY | 1 Eng. Div DNR | 2 Hydro Survay | 3 Mich. Highway | 4 MSU | 5 ERIM | 6 Abrams | 7 Forest Service | 8 ASCS | 9 SCS | 10 Army Corps | 11 USGS | 12 High Alt.USGS | 13 National Archives | 14 Capit 15 Areo 16 Chica |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alcona | 52, 68 | 38 | 64 | 38,52,54 | 74C | | 60gIR P68,P51 | P52gIR P63 | | 73,74 | 71 1 | 53x | 38 | |
| Alger | 39,54,64 | 39 | 64IR | 40 | 74C | | P64gIR P70xBW P72gC | P53gIR | | 73,74 | P53h P64i | 53 | 39 | |
| Allegan | | 38 | 67 | 38,50,56 | 74C | | | 50,55,60 67,74 | | 73,74 | 57i | 56x | 38 | |
| Alpena | 52,68 | 38 | 63 | 38,52 | 74C | | P51 P60gIR P68zBW | 52gIR,63 | | 73,74 | 52,71 | 53x | 38 | Ca 72uBW |
| Antrim | 52,55 | 38 | 63 | 38 | 74C | 62gBW | | 52gIR 63,73 | | 73,74 | P52o P54h | 53x | 38 | |
| Arenac | 52 | P52 | 65 | 52 | 74C | | | 52gIR,58 65,70v | | 73,74 | P65e | 53x | 38 | |
| Baraga | 55,64,68 | 38 | 68 | 38,55 | 74C | | P60gIR | P54gIR P68 | | 73,74 | 51n | 53v,53x | | |
| Bay | | P55 | 63 | P38,63,50 | 74C | 60a | | 50,55,63 69 | | 73,74 | 59h,59n 66e,73o | 53x | 38 | |
| Benzic | 52 | 38 | 65 | 52,58 | 74C | | | 52gIR,58 65,73v | | 73,74 | 54h | 53x | 38 | Ca72nBW |
| Berrien | 69 | 38 | 67 | 35,50,55 60,61 | 74C | 58b,60b | | 50,55,60 67,74 | | 73,74 | 69m | P52y | P35,38 | |
| Charlevoix | 52 | 38 | 65 | 55,65 | 74C | 62gBW | | 55gIR P65,73v | | 73,74 | P52o P54h | 53x | 38 | |
| Cheboygan | 52,68 | 38 | 63 | 38,52,56 63 | 74C | | | 52gIR 63,73v | | 73,74 | 54h,56h | 53x | 38 | |
| Chippewa | 53,64 | 39,P54 | 64IR | 39 | 74C | 53 1 | 64IR P69e 70xBW 72gC | 53gIR | | 73,74 | P52h 56h | 53x | 39 | |

| COUNTY | 1 Eng.Div. DNR | 2 Hydro. Survay | 3 Mich. Highway | 4 MSU | 5 ERIM | 6 Abrams | 7 Forest Service | 8 ASCS | 9 SCS | 10 Army Corps | 11 USGS | 12 High Alt.USGS | 13 National Archives | 14 Capit. 15 Areo 16 Chica. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delta | 53,54,64 | 39 | | 39 | 74C | | P64IR P70xBW P72gC | P53gIR P54gIR | 73 | 73,74 | 53h 54h | 53x | 39 | |
| Emmet | 52 | 38,53 | 65 | 38,52,58 65 | 74C | | | 53eIR,58 65,73 | | 73,74 | 54h,56h | 53x | 38 | |
| Gogebic | 51 | | 60IR | 39 | 74C | | 60gIR | | | 73,74 | P51,P52 54o, | 56x | 39 | |
| Grand Traverse | 52 | | 64IR | 38 | 74C | 71BW | | 64,73v | | 73,74 | 54h | 53x | 38 | Ca 72nBW |
| Houghton | 51,54,63 | | 63 | 38,54 | 74C | | P60gIR 64IR | P54gIR | | 73,74 | P53h,P38 | 53x | | |
| Huron | 68 | 38 | 64 | 37,41,49 | 74C | | | 49,56, 64,72v | 72w | 73,74 | P59h P69 | 53x | 38,41 | |
| Iosco | 38,52,68 | 38 | P38,P52 | 38,52 | 74C | | P60gIR P68 | P52gIR P63 | | 73,74 | P65e | 53x | 38 | |
| Keweenaw | 54,63,64 | 38,P43 | | 38 | 74C | | 64IR | P54gIR | | 73,74 | P38,56e | | | |
| Leelanau | 52 | 38 | 63 | 38,52 | 74C | | | 53gIR P63,73v | | 73,74 | 54h | 53x | 38 | |
| Luce | 52,64 | 39 | 64IR | 39 | 74C | | 64IR | 53gIR | | 73,74 | 64 | 53x | 39 | |
| Mackinaw | 52,53,64 | P30 | 64IR | 39 | 74C | P30 | 64IR, 70xBW 72gC | 53gIR | | 73,74 | P56h P73m | 53x | 39 | |
| Macomb | | 37 | 70 | 37,40, 55,64 | 74C | 64eBW 70oBW | | P55,P64 73v | | 73,74 | 73o 51n,67o | 53x | 38,40 | |
| Manistee | 52 | 38 | 65 | 39,58 | 74C | 70eBW | | 53gIR,58 65,73 | | 73,74 | 54h | 53x | 38 | |
| Marquette | 54,55,64 | 39 | 64IR | 39 | 74C | P49b | 64IR | 54gIR | | 73,74 | P51o P54h | P53v 53x | 39 | |
| Mason | 51,52,53 | 38 | 65 | 52,68 | 74C | | P55gIR P65gBW P71xC | 52,58 65,72v | | 73,74 | P55h | 53x | 38 | |

| COUNTY | 1 Eng.Div. DNR | 2 Hydro. Survay | 3 Mich. Highway | 4 MSU | 5 ERIM | 6 Abrams | 7 Forest Service | 8 ASCS | 9 SCS | 10 Army Corps | 11 USGS | 12 High Alt.USGS | 13 National Archives | 14 Capit. 15 Areo 16 Chica. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Menominee | 53,54,64 | 39 | 64IR | 39 | 74C | | 64IR | 54gIR | | 73,74 | 54h | 53x | 39 | Ar 51gIR |
| Monroe | | 42 | 70 | 37,40,50 55,57,64 | 74C | P70oBW | | 50,55,64 | | 73,74 | 51n,67o 73o | P60x | 38,40 | Ch 71BW |
| Muskegon | 69 | 55 | 68 | 38,50 61,62 | 74C | 68gBW 68uBW | | 50,55,62 68,74 | 55,62 | 73,74 | P55h P69f | 53x | 38 | |
| Oceana | 52 | 38 | 65 | 38,39 52,58 | 74C | P54C | | 51,58 65,72v | | 73,74 | | 53x | 38 | |
| Ontonagon | 51,54 63,64 | P38,P39 P46 | | 38,39 | 74C | | P60gIR, 64IR, 70BW&C | P54gIR | | 73,74 | P48r P52n P54o | P53x | P39 | Ar P51g Ch P58f |
| Ottawa | | | 68 | 38,50,55 60-61 | 74C | | | 50,55 61,74 | 68a | 73,74 | P57i 69 1 | P53x,P56x | 38 | |
| Presque Isle | 52,68 | | 64 | 38,52 | 74C | | | 52gIR,64 | | 73,74 | P54h,P56h P71 1 | 53x | 38 | Ca 72nBW |
| St. Clair | | P41,57 | 70 | 37-38,41 | 74C | 62g, P70oBW | | 50,57,64 | 70 | 73,74 | P51n,P59h P73o | 53x | 38,41 | |
| Sanilac | | | 63 | 38,P41 49,55 | 74C | | | 49,55 63,70v | | 73,74 | 59h | 53x | 38,41 | |
| Schoolcraft | 39,53,64 | 39 | 64IR | 39 | 74C | | 64IR | P53gIR P54gIR | | 73,74 | P53h P71f | 53x | 39 | |
| Tuscola | | P41 | 63 | 38,41 49,55 | 74C | | | 49,55 63,70v | | 73,74 | P59h P73o | 53x | 38,41 | |
| Van Buren | | P56 | 67 | 38,50 55,60 | 74C | | | 50,55,60 67,74 | | 73,74 | | 56x | 38 | |
| Wayne | | | 70 | 37,40 64 | 74C | 70oBW | | P57 P64 74 | | 73,74 | P51h P52h 67o 73o | 53x | 37,P40 | |

IN-STATE AGENCIES

1. Engineering Division
   Department of Natural Resources
   Stevens T. Mason Building
   Lansing, Michigan 48926

2. Hydrological Survey
   Department of Natural Resources
   Stevens T. Mason Building
   Lansing, Michigan 48926

3. Michigan State Highway Commission
   P. O. Drawer K
   Lansing, Michigan 48904

4. Michigan State University (holds old USDA photos)
   Contact: Dr. D. Brunnschweiler
   Department of Geography
   Michigan State University
   East Lansing, Michigan 48823

5. ERIM (Environmental Research Institute of Michigan)

   ERIM holds many types of imagery of various segments of Michigan coastline, most of which have not been included in the index chart. Write for their index, "Aerial Coverage State of Michigan Shoreline," which lists all coastal imagery they hold. They also have a handy reference, "Landuse Mapping for the State of Michigan."
   Write to: Environmental Research Institute of Michigan
   Ann Arbor, Michigan 48107

6. Abrams Aerial Survey Corporation
   P. O. Box 536
   Lansing, Michigan 49803

7. U. S. Forest Service
   U. S. Department of Agriculture
   Contact: Regional Forest Experiment Stations for national forest of interest.

8. Agricultural Stabilization and Conservation Service (ASCS)
   1405 South Harrison
   East Lansing, Michigan 48823
   Also contact: Field offices in area of interest.

9. Soil Conservation Service
1405 South Harrison
East Lansing, Michigan 48823
Also contact: Field offices in area of interest.

10. U. S. Army, Corps of Engineers
Contact: Carl E. Lamphere
U. S. Army Engineer District, Detroit
P. O. Box 1027
Detroit, Michigan 48231
(313/226-6816)

11. NOAA
Contact: Floyd R. Watts
Lake Survey Center
NOAA
630 Federal Building
Detroit, Michigan 48226

This office holds many photographs of harbors, rivers, and some coastal stretches taken by the Air Force and Abrams between 1966 and 1970. Their photos and catalog of Aerial Photography may be looked over in the office. (Phone: 313/226-7082).

OUT-STATE AGENCIES

1. Agricultural Stabilization and Conservation Service
   To order photographs or for indexes contact:
   ASCS
   Eastern Aerial Photography Laboratory
   45 South French Broad Avenue
   Asheville, North Carolina 28801
   Also see In-State listing.

2. Soil Conservation Service
   Contact: Cartographic Division
   Soil Conservation Service
   Federal Center Building
   Hyattsville, Maryland 20782

3. U. S. Army, Corps of Engineers
   The many district offices of the Army Corps of Engineers hold many photographs, mostly harbors and rivers but some coastal stretches.
   Also contact: U. S. Army, Corps of Engineers
   Coastal Engineering Research Center

   Or: National Technical Information Service
   Attn: Operations Division
   5285 Port Royal Road
   Springfield, Virginia 22151

4. USGS
   Contact: Map Information Office
   U. S. Geological Survey
   Washington, D. C. 20242

   Or: National Cartographic Information Center
   USGS National Center
   Mail Stop #507
   Reston, Virginia 22092

   Or: The Regional Mapping Center
   Rolla, Missouri

5. High Altitude, USGS
   High altitude imagery is available for much of Michigan.
   Contact: U. S. Department of Interior
   EROS Data Center
   Sioux Falls, South Dakota 57198
   EROS Data Center also handles all Earth Resources Technology Satellite imagery and Skylab imagery. Some of this high altitude imagery may be seen at ERIM (see In-State listing).

6. National Archives

Most photographic coverage flown prior to 1940 by the ASCS, SCS, and USGS is held by the National Archives. All imagery is listed in the publication, "Special List No. 25, Aerial Photography in the National Archives."

Contact: National Archives and Records Service
Cartographic Branch
General Services Administration
Washington, D. C. 20408

7. Capital Air Survey
10265 Franklin Avenue
Franklin Park, Illinois 60131

8. Aero Service Corporation
210 East Courtland Street
Philadelphia, Pennsylvania

9. Chicago Aerial Survey
10265 Franklin Avenue
Franklin Park, Illinois 60131

# APPENDIX II

## LIST OF PHOTOS USED

## LIST OF PHOTOS USED

| Area | Year | Photo Identification Number | Date | Source |
|---|---|---|---|---|
| 1 | 1938 | BEI-IR-30,31 | 6-30-38 | MSU |
| | 1962 | BEI-9AA-89 | 6-13-62 | MSU |
| | 1968 | BEI-2JJ-150,151,152,153 | 5-8-68 | Highway Dept. |
| | 1970 | 000084,85,86 | 6-70 | DNR |
| 2 | 1968 | BEI-2JJ-244,245 | 5-8-68 | Highway Dept. |
| | 1970 | 000095,96 | 6-70 | DNR |
| 3 | 1938 | BEI-5-39,140 | 6-23-38 | MSU |
| | 1968 | BEI-2JJ-242,243 | 8-68 | Highway Dept. |
| | 1970 | 000098 | 6-70 | DNR |
| | 1974 | Not numbered, 2 images | 4-74 | ERIM |
| 4 | 1968 | BEI-2JJ-252,253 | 5-8-68 | Highway Dept. |
| | 1970 | 000101,102,103 | 6-70 | DNR |
| | 1974 | Not numbered, 4 images | 4-74 | ERIM |

# APPENDIX III

## MEASUREMENTS FOR ALL SITES

MEASUREMENTS FOR ALL SITES

| | | Year | Control point to bluff line (feet) | Control point to toe line (feet) | Control point to water line (feet) | Control point to bar line (feet) |
|---|---|---|---|---|---|---|
| | 1 | 1938 | 1762.7 | 3397.9 | 3533.7 | 3648.0 |
| NS* | | 1962 | 1736.4 | 3316.8 | 3426.2 | 3844.3 |
| | | 1968 | 1715.0 | 3225.1 | 3329.1 | 3459.2 |
| | | 1970 | 1716.0 | 3192.7 | 3277.2 | 3411.6 |
| | 2 | 1938 | 1690.5 | 1786.7 | 2021.0 | 2137.4 |
| | | 1962 | [1690.0] | --- | 1827.0 | 2090.0 |
| | | 1968 | 1641.9 | [1736.0] | 1892.0 | 2003.0 |
| | | 1970 | [1669.0] | 1764.0 | 1824.0 | 1958.0 |
| | 3 | 1938 | 1149.9 | 1187.7 | 1349.8 | 1515.5 |
| NS | | 1962 | 1106.1 | 1129.8 | 1247.4 | 1534.9 |
| | | 1968 | 1077.5 | 1185.4 | 1107.8 | 1599.7 |
| | 4 | 1968 | 279.6 | [314.0] | 386.5 | 518.3 |
| | | 1970 | 259.3 | [311.6] | 394.1 | 660.0 |
| | 5 | 1968 | 432.7 | [496.6] | 558.2 | 669.0 |
| | | 1970 | 495.0 | [483.9] | 483.9 | 794.2 |
| | 6 | 1968 | 192.3 | [252.9] | 326.2 | 588.1 |
| | | 1970 | 180.5 | [209.8] | 254.1 | 464.9 |
| | 7 | 1938 | 435.9 | 537.0 | 629.4 | 850.1 |
| | | 1968 | 408.7 | 460.8 | 582.6 | 802.6 |
| NS | | 1970 | [537.4] | --- | 499.5 | --- |
| | | 1974 | 407.3 | 463.8 | 501.6 | --- |
| | 8 | 1938 | 640.5 | 740.2 | 802.5 | 1060.3 |
| | | 1968 | 639.6 | 687.5 | 730.2 | --- |
| NS | | 1970 | --- | --- | --- | --- |
| | | 1974 | 633.7 | 734.9 | 734.9 | --- |
| | 9 | 1938 | 520.4 | 581.5 | 683.7 | 627.5 |
| | | 1968 | 501.5 | 551.7 | 611.3 | 878.7 |
| NS | | 1970 | 499.6 | 547.9 | 574.7 | 1133.4 |
| | | 1974 | 483.2 | 577.3 | 577.3 | --- |
| | 10 | 1938 | 488.1 | 564.2 | 637.4 | 901.4 |
| | | 1968 | 459.7 | 523.6 | 558.5 | 820.8 |
| NS | | 1970 | [504.4] | --- | 556.2 | 741.3 |
| | | 1974 | 459.7 | 568.3 | 568.3 | --- |

*NS indicates years with no stereo coverage.

MEASUREMENTS FOR ALL SITES, Cont.

| | Year | Control point to bluff line (feet) | Control point to toe line (feet) | Control point to water line (feet) | Control point to bar line (feet) |
|---|---|---|---|---|---|
| 11 | 1938 | 803.6 | 993.6 | 1084.5 | 1317.2 |
| | 1968 | 781.3 | 834.8 | 997.9 | 1220.2 |
| NS | 1970 | [907.4] | [985.8] | 1020.6 | 1220.9 |
| | 1974 | 769.2 | 1029.7 | 1081.5 | --- |
| 12 | 1968 | 658.3 | 788.2 | 881.7 | 1105.8 |
| | 1970 | [627.9] | 769.0 | 946.3 | 1125.8 |
| | 1974 | 655.0 | 801.5 | 955.0 | 1158.0 |
| 13 | 1968 | 726.6 | 788.2 | 881.7 | 992.3 |
| | 1970 | [685.9] | 750.9 | 803.1 | --- |
| | 1974 | 710.0 | 780.0 | 780.0 | --- |
| 14 | 1968 | 637.2 | 759.2 | 857.1 | 964.3 |
| | 1970 | [572.8] | 732.6 | 764.9 | 869.3 |
| | 1974 | 601.0 | 771.8 | 771.8 | --- |

